PROPOSED INTERFACE

REVISION NOTICE (PPIRN)

To

IS-GPS-705

For

Improved Clock and Ephemeris (ICE) Message

PIRN-705-001

23 July 2004

Distribution A. Approved for public release; distribution unlimited.

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Description of Change

1. This PIRN provides requirements and descriptions for the Improved Clock and Ephemeris (ICE) message parameters to be transmitted on L5.

2. This PIRN incorporates the results from the ICWG meeting held at ARINC in El Segundo, CA in March 2004. It also incorporates appropriately dispositioned comments submitted by the ICWG members for PPIRN-705-001 which was previously distributed in November 2003.

3. The proposed changes are described in this PIRN as follows;

   deletion   -   strikeout,
   addition   -   italic.

   The changes are described using the extracts from IS-GPS-705, dated 24 November 2003.

4. For the ICE message update, the entire Appendix II is included in this PIRN and only additions are shown with italic. Deletions are not shown due to extensiveness of deletions. Once authenticated, it will replace the entire Appendix II of the currently baselined IS-GPS-705, dated 24 November 2003.

1. SCOPE

1.1 Scope. This Interface Specification (IS) defines the requirements related to the interface between the Space Segment (SS) of the Global Positioning System (GPS) and the ~~N~~*n*avigation User~~s~~ *Segment (US)* of the GPS for *radio frequency (RF) link 5*~~the (~~L5~~) Navigation Signal~~.

1.2 IS Approval and Changes. ARINC Engineering Services, LLC has been designated the Interface Control Contractor (ICC), and is responsible for the basic preparation, approval, distribution, ~~and~~ retention*, and Interface Control Working Group (ICWG) coordination* of the IS in accordance with ~~YEN 75-13B~~*GP-03-001*. The Navstar GPS Joint Program is the ~~only signatory~~ necessary *authority* to make this IS effective. The *Joint Program Office (*JPO*)* administers approvals under the auspices of the Configuration Control Board (CCB), which is governed by ~~CZ Operating Instruction 63-1101~~*the appropriate JPO Operating Instruction (OI)*. Military organizations and contractors are represented *at the CCB* by their respective segment member. All civil organizations *and public interest* are represented by the Department of Transportation *representative of the GPS JPO*~~member (SMC/GPC)~~.

Propos*al*~~ed~~ *to* change~~s to~~ the approved version of this IS can be ~~initiated~~*submitted* by any *ICWG* participating organization *to the GPS JPO and/or the ICC*. ~~The ICC is responsible for maintaining a distribution list of all reviewing organizations and distributing submitted changes.~~ The ICC is responsible for the preparation of the change paper and change coordination, in accordance with ~~YEN 75-13B~~*GP-03-001*. *The ICC prepares the change paper as a Proposed Interface Revision Notice (PIRN) and is responsible for coordination of PIRNs with the ICWG. The ICWG coordinated PIRN must be submitted to* ~~and presentation of the change before~~ the ~~NAVSTAR~~ GPS *JPO CCB for review and approval*~~Joint Program Office Configuration Control Board in accordance with CZ OI 63-1101~~.

~~Any exception to this IS or its changes shall be administered in the form of comment submitted through the respective Configuration Control Board member. Standard practices mandated by CZ Operating Instruction 63-1101 include compiling all submitted comments and indicating the project officer's proposed resolution. Exceptions of the type stating applicability of this IS to a particular contract shall be submitted through the Procuring Contracting Officer for that contract.~~

The ICWG r~~R~~eview *period*~~cycle~~ for all Proposed Interface Revision Notices (PIRNs) is 45 days after receipt by individual addressees.~~ unless a~~*A* written request *to extend the review period may be*~~for a waiver is~~ submitted to the ICC *for consideration*.~~ Non-responses are interpreted as acceptance.~~

2. APPLICABLE DOCUMENTS

2.1 <u>Government Documents</u>. The following documents of the issue specified contribute to the definition of the interfaces between the GPS Space Segment ~~(GPS SS)~~ and the GPS *n*~~N~~avigation User Segment (US), and form a part of this IS to the extent specified herein.

<u>Specifications</u>

    Federal

        None

    Military

        None

    Other Government Activity

        None

<u>Standards</u>

    Federal

        None

    Military

        None

<u>Other Publications</u>

ICD-GPS-200 current issue	Navstar GPS Space Segment / Navigation User Interfaces
~~YEN 75-13B~~*GP-03-001* ~~21 Oct 1988~~*14 Nov 2003*	*GPS* Interface Control Working Group (ICWG) Charter
~~CZ OI 63-1101~~ ~~15 Feb 2002~~	~~SMC/CZ Operating Instructions~~

3.2 <u>Interface Identification</u>. The carriers of the L5 L-band link are modulated by two bit trains in phase quadrature. One is a composite bit train generated by the modulo-2 addition of a pseudo-random noise (PRN) ranging code, a synchronization sequence (see paragraph 3.3.3.1.2), and the downlink system data (referred to as NAV data), and the second is modulated with a PRN ranging code and synchronization sequence (see paragraph 3.3.2.3) that differ from those used with the NAV data.

3.2.1 <u>Ranging Codes</u>. Two PRN ranging codes are transmitted on L5: the in-phase code (denoted as the I5-code); and the quadraphase code (denoted as the Q5-code). Code-division-multiple-access techniques allow differentiating between the SVs even though they all transmit at the same L5 frequency. The SVs shall transmit intentionally "incorrect" versions of the I5 and the Q5-codes when needed to protect the users from receiving and utilizing anomalous NAV signals. These two "incorrect" codes are termed non-standard I5 (NSI5) and non-standard Q5 (NSQ5) codes.

3.2.1.1 <u>L5-Codes</u>. The PRN ranging codes $I5_i(t)$ and $Q5_i(t)$ for SV ID number i are independent, but time synchronized, 1 millisecond in length, a chipping rate of 10.23 Mbps. For each code, the 1-millisecond sequences are the modulo-2 sum of two sub-sequences referred to as XA and XB_i; their lengths are 8,190 chips and 8,191 chips, respectively that restart to generate the 10,230 chip code. The XB_i sequence is selectively advanced, thereby allowing the basic code generation technique to produce ~~a set of 74 (37 I5 and 37 Q5)~~ different code sequences of 1-millisecond in length. Of these, 32 pairs are *currently* designated for use by SVs~~, and~~~~while the remaining~~ 5 pairs are *currently* reserved. Assignment of these code phase segments by SV-ID number (or other use) is given in Table 3-I. SV ID numbers and PRN are identical to those for the L1 and L2 signals as specified in ICD-GPS-200.

The 74 codes are a selected subset of over 4,000 possible codes that could be generated using the selective advance. The remaining codes are reserved for *future use of additional SVs and/or* other L5 signal applications such as Satellite-Based Augmentation System (SBAS) satellite signals.

3.2.2 <u>NAV Data</u>. The system data, $D_5(t)$, includes SV ephemerides, system time, SV clock behavior data, status messages and time information, etc. The 50 bps data is coded in a rate 1/2 convolutional coder. The resulting 100 symbols per second (sps) symbol stream is modulo-2 added to the I5-code only; the resultant bit-train is used to modulate the L5 in-phase (I) carrier. The content and characteristics of the system data, $D_5(t)$, are given in Appendix II of this document. In general, the data content is *very similar to*~~based on~~ that modulated on ~~the C/A codes in the L1 and~~ L2 *C* channel~~s~~ of the SV~~, with data specific to the L5 signal added, and a different error detection encoding used~~.

The L5 quadraphase (Q5) carrier has no data.

3.3.1.8 Signal Coherence. L5 transmitted signals for a particular SV shall be coherently derived from the same on-board frequency standard. All PRN signals shall be clocked coherently with the P(Y)-code signal transitions. On the L5 channel the chip transitions of the two modulating signals (i.e., that containing the I5-code and that containing the Q5-code) shall be such that the average time difference between the transitions does not exceed 10.0 nanoseconds (two-sigma).

The average duration of "+1" chips and "-1" chips shall be equal to within 1 nanosecond (2-sigma).

3.3.1.9 Signal Polarization. The transmitted signal shall be right-hand circularly polarized (RHCP). For the angular range of ±14.3 degrees from boresight, L5 ellipticity shall be no worse than 2.4 dB. Nominal values are listed in section 6.3.3.

3.3.2 PRN Code Characteristics. The characteristics of the I5- and the Q5-codes are defined below in terms of their structure and the basic method used for generating them. Figures 3-2 and 3-3 depict simplified block diagrams of the scheme for generating the 10.23 Mbps $I5_i(t)$ and $Q5_i(t)$ patterns, and for modulo-2 summing the I5 patterns with the NAV bit train, $D_5(t)$, which is rate 1/2 encoded and clocked at 100 sps. In addition, the 100 sps symbols are modulated with a 10-bit Neuman-Hofman code that is clocked at 1 kHz. The resultant composite bit trains are then used to modulate the L5 in-phase carrier. The Q5-code is modulated with a 20-bit Neuman-Hofman code that is also clocked at 1 kHz.

3.3.2.1 Code Structure. The $I5_i(t)$ pattern (I5-code) and the $Q5_i(t)$ pattern (Q5-code) are both generated by the modulo-2 summation of two PRN codes, XA(t) and $XBI_i(n_{Ii}, t)$ or $XBQ_i(n_{Qi}, t)$, where n_{Ii} and n_{Qi} are initial states of XBI_i and XBQ_i for satellite i. There are over 4000 unique L5 codes generated using different initial states of which 74 are *currently* assigned and identified in Table 3-I using the same basic code generator.

3.3.4 <u>GPS Time and SV Z-Count</u>. GPS time is established by the Operational Control System (OCS) and is referenced to a *Coordinated Universal Time (*UTC*)* (as maintained by the U.S. Naval Observatory *(UTC(USNO))*) zero time-point defined as midnight on the night of January 5, 1980/morning of January 6, 1980. GPS time is the ensemble of corrected composite L1/L2 P(Y) SV times, corrected via the clock corrections in the L1 and L2 NAV data and the relativity correction. The largest unit used in stating GPS time is one week defined as 604,800 seconds, concatenated with the GPS week number. GPS time may differ from UTC because GPS time is a continuous time scale, while UTC is corrected periodically with an integer number of leap seconds. There also is an inherent but bounded drift rate between the UTC and GPS time scales. The OCS controls the GPS time scale to be within one microsecond of UTC (modulo one second).

The L5 NAV data contains the requisite data for relating GPS time to UTC. The accuracy of this data during the transmission interval will be such that it relates GPS time to UTC *(USNO)* to within 90.0 nanoseconds (one sigma). This data is generated by the CS (or provided to the CS); therefore, the accuracy of these relationships may degrade if for some reason the CS is unable to upload data to an SV.

In each SV the X1 epochs of the P-code of the L1 and L2 offer a convenient unit for precisely counting and communicating time. Time stated in this manner is referred to as Z-count, which is given as a 29-bit binary number consisting of two parts as follows:

a. The binary number represented by the 19 least significant bits of the Z-count is referred to as the time of week (TOW) count and is defined as being equal to the number of X1 epochs that have occurred since the transition from the previous week. The count is short-cycled such that the range of the TOW-count is from 0 to 403,199 X1 epochs (equaling one week) and is reset to zero at the end of each week. The TOW-count's zero state is defined as that X1 epoch which is coincident with the start of the present week. This epoch occurs at (approximately) midnight Saturday night-Sunday morning, where midnight is defined as 0000 hours on the ~~Coordinated Universal Time (~~UTC~~)~~ scale, which is nominally referenced to the Greenwich Meridian. Over the years the occurrence of the "zero state epoch" may differ by a few seconds from 0000 hours on the UTC scale since UTC is periodically corrected with leap seconds while the TOW-count is continuous without such correction. A truncated version of the TOW-count, consisting of its 17 most significant bits, is contained in each of the six-second messages of the L5 downlink data stream; the relationship between the actual TOW-count and its truncated message version is illustrated by Figure 3-9.

b. The ten most significant bits of the Z-count are a modulo-1024 binary representation of the sequential number assigned to the current GPS week (see paragraph 6.2.4). The range of this count is from 0 to 1023 with its zero state being defined as the GPS week number zero and every integer multiple of 1024 weeks, thereafter (i.e. 0, 1024, 2048, etc.).

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6.   NOTES

6.1   <u>Acronyms</u>

AFMC	-	Air Force Materiel Command
AFSPC	-	Air Force Space Command
ASCII	-	American Standard Code for Information Interchange
A-S	-	Anti-Spoof
bps	-	bits per second
BPSK	-	Bi-Phase Shift Key
C/A	-	Course/Acquisition
CNAV	*-*	*Civil Navigation*
CRC	-	Cyclic Redundancy Check
CS	-	Control Segment
dB	-	Decibel
dBW	-	Decibels with respect to 1 Watt
DoD	-	Department of Defense
ECEF	-	Earth-Centered, Earth-Fixed
EOL	-	End of Life
FEC	-	Forward Error Correction
GNSS	*-*	*Global Navigation Satellite System*
GPS	-	Global Positioning System
Hz	-	Hertz
I5	-	Inphase Code on L5 Signal
ICC	-	Interface Control Contractor
ICD	-	Interface Control Document
ID	-	Identification
IODC	-	Issue of Data, Clock
IS	-	Interface Specification
ISC	-	Inter-Signal Correction
LSB	-	Least Significant Bit
MSB	-	Most Significant Bit
NAV	-	Navigation
NSI5	-	Non-Standard I-Code
NSQ5	-	Non-Standard Q-Code
OCS	-	Operational Control System

[cont. Section 6.1]

PIRN	-	Proposed Interface Revision Notice
PRN	-	Pseudo-Random Noise
P(Y)	-	Precise (Anti-Spoof) Code
Q5	-	Quadraphase code on L5 Signal
RF	-	Radio Frequency
RHCP	-	Right Hand Circular Polarization
RMS	-	Root Mean Square
SBAS	-	Space-Based Augmentation System
sps	-	Symbols per Second.
SIS	-	Signal In Space
SS	-	Space Segment
SV	-	Space Vehicle
TBD	-	To Be Determined
TBS	-	To Be Supplied
TOW	-	Time Of Week
URA	-	User Range Accuracy
US	-	User Segment
UTC	-	Coordinated Universal Time
WN	-	Week Number
WN_e	-	Extended Week Number

20   APPENDIX II. GPS NAVIGATION DATA STRUCTURE FOR *L5 C*NAV DATA, D$_5$(t)

20.1 Scope. This appendix describes the specific GPS *L5 civil* navigation (*C*NAV) data structure denoted by, D$_5$(t).

20.2 Applicable Documents.

20.2.1 Government Documents.
In addition to the documents listed in paragraph 2.1, the following documents of the issue specified contribute to the definition of the NAV data related interfaces and form a part of this Appendix to the extent specified herein.

      Specifications
          None
      Standards
          None
      Other Publications
          None

20.2.2 Non-Government Documents.
In addition to the documents listed in paragraph 2.2, the following documents of the issue specified contribute to the definition of the NAV data related interfaces and form a part of this Appendix to the extent specified herein.

      Specifications
          None
      Other Publications
   None

20.3 Requirements.

20.3.1 Data Characteristics. The L5 channel data stream mostly contains the same data as the L2 *C* channel. The data stream shall be transmitted by the SV on the L5 channel at the rate of 50 bps with rate 1/2 FEC resulting in 100 sps. Also, the *CNAV* data stream uses a different parity algorithm.

20.3.2 Message Structure. As shown in Figures 20-1 through 20-1*4*, the L5 *CNAV* message structure utilizes a basic format of six-second 300-bit long messages. Each message contains a Cyclic Redundancy Check (CRC) parity block consisting of 24 bits covering the entire six-second message (300 bits) (reference Section 20.3.5).

Message type 0 (zero) is defined to be the default message. To protect users from message generation failures, the SV shall replace the content of each affected message type with the default message type. In the event that a particular message is not assigned (by the CS) a particular message type for broadcast, the SV shall generate and broadcast the default message type in that message slot.

Currently undefined and unused message types are reserved for future use.

20.3.3 Message Content. Each message starts with an 8-bit preamble – 10001011, followed by a 6-bit PRN number of the transmitting SV, *a 6-bit* message type ID, with a range of 0 (000000) to 63 (111111), and the 17-bit message *Time of Week* (TOW) count. When the value of the message TOW count is multiplied by 6, it represents SV time in seconds at the start of the next 6-second message. An "alert" flag, when raised (bit 38 = "1"), indicates to the user that the SV User Range Accuracy (URA) *and/or the SV User Differential Range Accuracy (UDRA)* may be worse than indicated in *the respective message types, and the SV should be used at the user's own risk. For each default message (Message Type 0), bits 39 through 276 shall be alternating ones and zeros and the message shall contain a proper CRC parity block.*
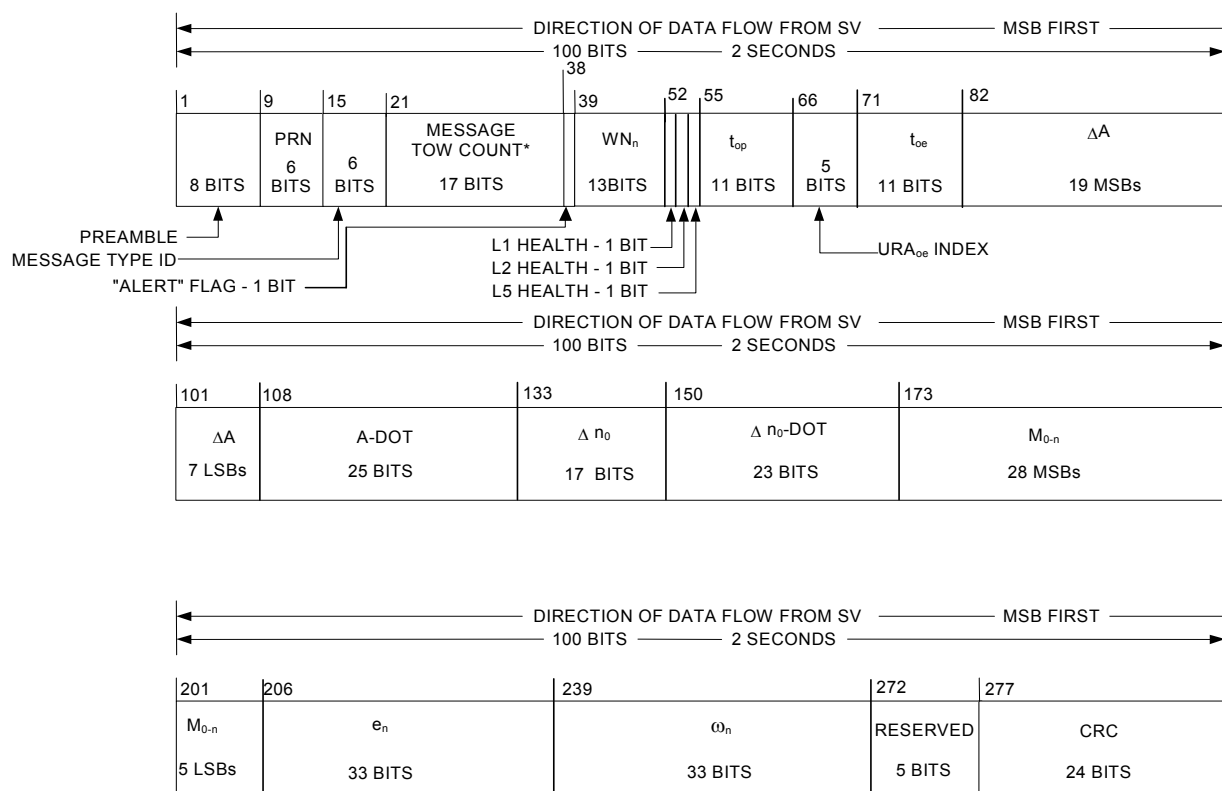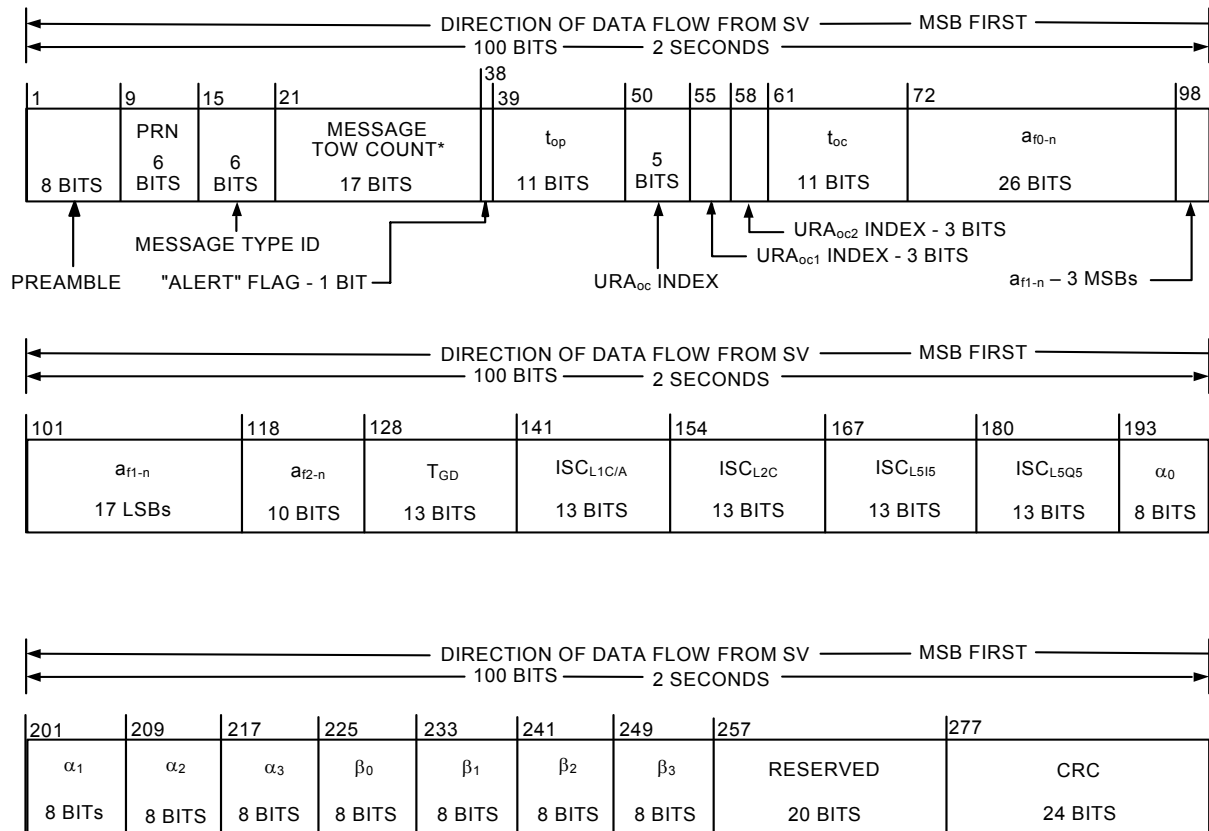
Figure 20-1. *Message type 10 - Ephemeris 1*
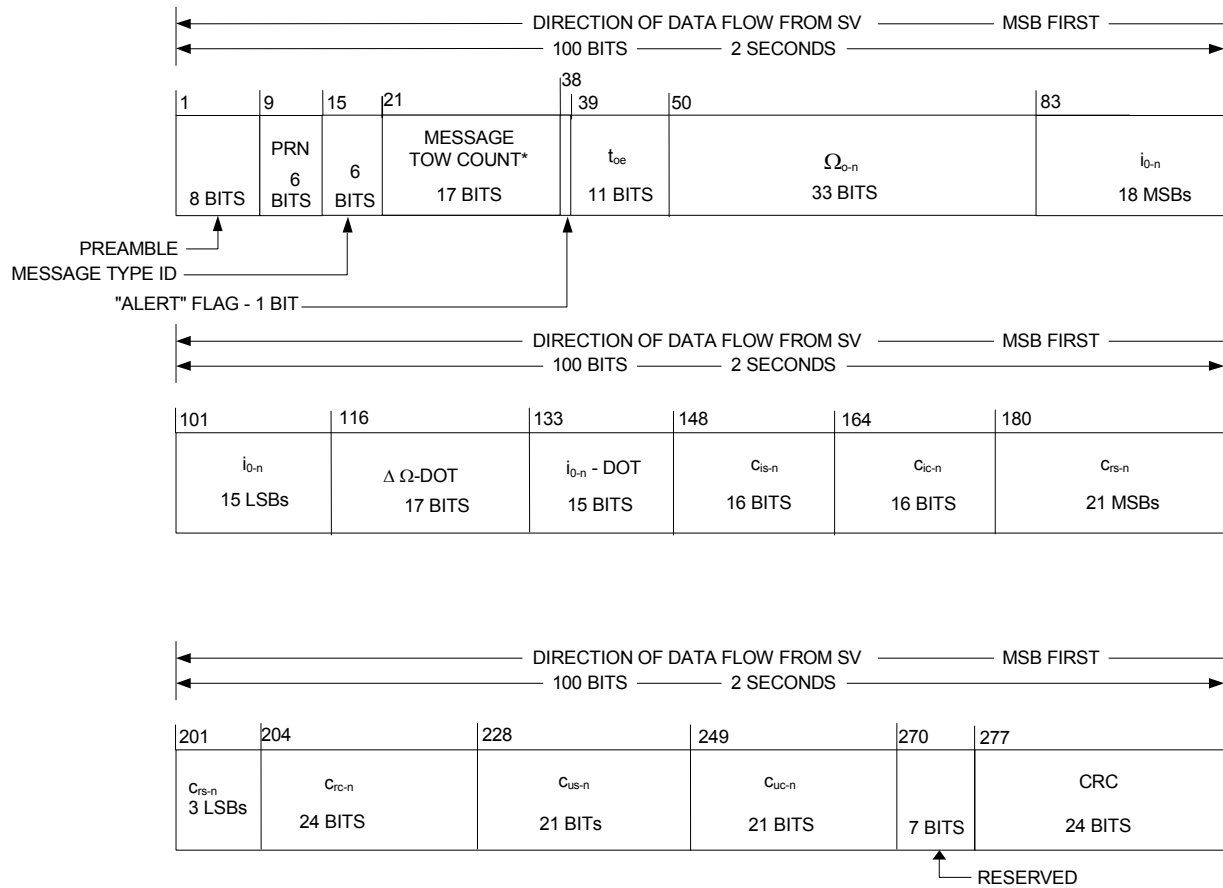
Figure 20-2. *Message type 11 - Ephemeris 2*

* MESSAGE TOW COUNT = 17 MSB OF ACTUAL TOW COUNT AT START OF NEXT 6-SECOND MESSAGE

DIRECTION OF DATA FLOW FROM SV — MSB FIRST
100 BITS — 2 SECONDS

1	9	15	21	38 / 39	50	55	58	61	72	98
8 BITS	PRN 6 BITS	6 BITS	MESSAGE TOW COUNT* 17 BITS	t_{op} 11 BITS	5 BITS			t_{oc} 11 BITS	a_{f0-n} 26 BITS	

PREAMBLE

MESSAGE TYPE ID

"ALERT" FLAG - 1 BIT

URA_{oc} INDEX

URA_{oc1} INDEX - 3 BITS

URA_{oc2} INDEX - 3 BITS

a_{f1-n} – 3 MSBs

DIRECTION OF DATA FLOW FROM SV — MSB FIRST
100 BITS — 2 SECONDS

101	118	128	141	154	167	180	193
a_{f1-n} 17 LSBs	a_{f2-n} 10 BITS	T_{GD} 13 BITS	$ISC_{L1C/A}$ 13 BITS	ISC_{L2C} 13 BITS	ISC_{L5I5} 13 BITS	ISC_{L5Q5} 13 BITS	α_0 8 BITS

DIRECTION OF DATA FLOW FROM SV — MSB FIRST
100 BITS — 2 SECONDS

201	209	217	225	233	241	249	257	277
α_1 8 BITs	α_2 8 BITS	α_3 8 BITS	β_0 8 BITS	β_1 8 BITS	β_2 8 BITS	β_3 8 BITS	RESERVED 20 BITS	CRC 24 BITS

* MESSAGE TOW COUNT = 17 MSB OF ACTUAL TOW COUNT AT START OF NEXT 6-SECOND MESSAGE

Figure 20-3. *Message type 30 - Clock, IONO & Group Delay*
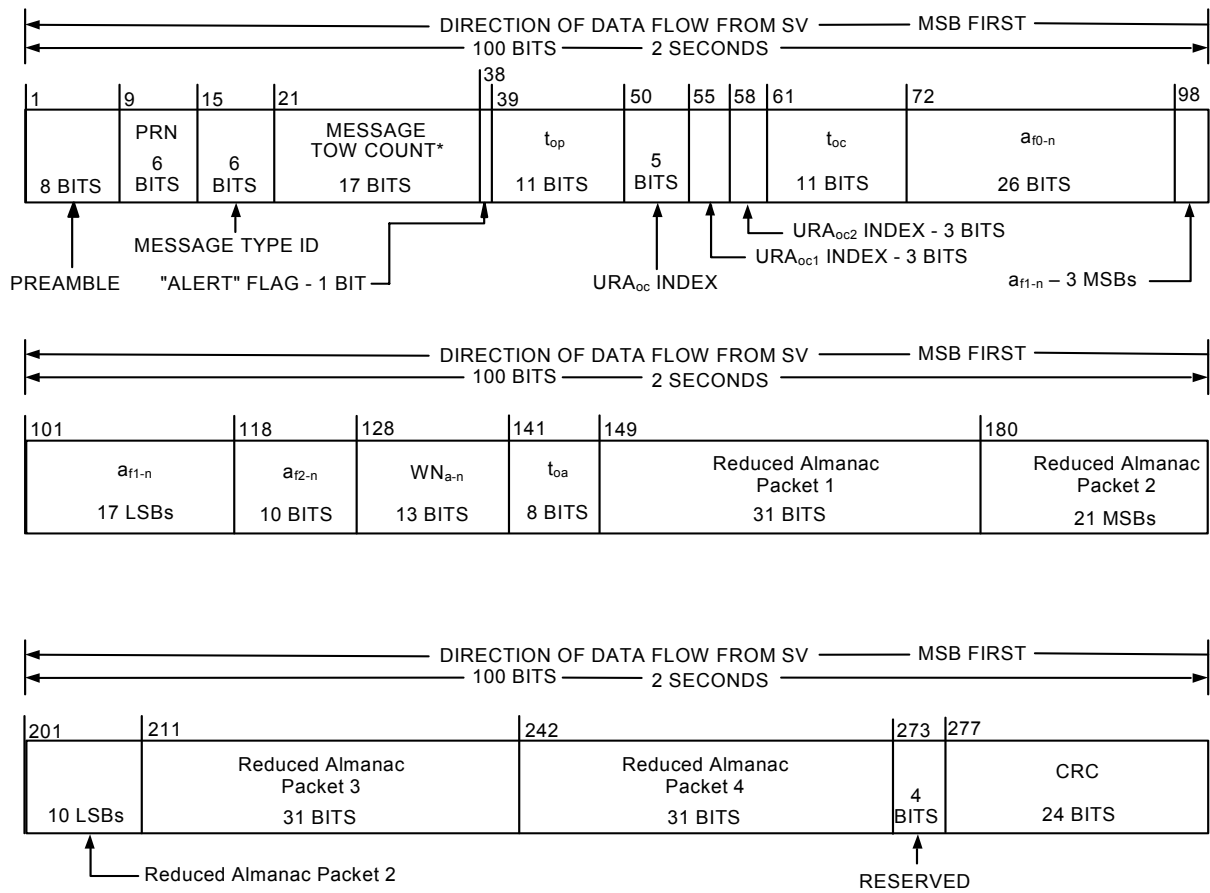
DIRECTION OF DATA FLOW FROM SV ——— MSB FIRST
——— 100 BITS ——— 2 SECONDS

1	9	15	21	38 39	50	55	58	61	72	98
8 BITS	PRN 6 BITS	6 BITS	MESSAGE TOW COUNT* 17 BITS	t_{op} 11 BITS	5 BITS			t_{oc} 11 BITS	a_{f0-n} 26 BITS	

PREAMBLE
MESSAGE TYPE ID
"ALERT" FLAG - 1 BIT
URA$_{oc}$ INDEX
URA$_{oc1}$ INDEX - 3 BITS
URA$_{oc2}$ INDEX - 3 BITS
a_{f1-n} – 3 MSBs

DIRECTION OF DATA FLOW FROM SV ——— MSB FIRST
——— 100 BITS ——— 2 SECONDS

101	118	128	141	149	180
a_{f1-n} 17 LSBs	a_{f2-n} 10 BITS	WN_{a-n} 13 BITS	t_{oa} 8 BITS	Reduced Almanac Packet 1 31 BITS	Reduced Almanac Packet 2 21 MSBs

DIRECTION OF DATA FLOW FROM SV ——— MSB FIRST
——— 100 BITS ——— 2 SECONDS

201	211	242	273	277
10 LSBs	Reduced Almanac Packet 3 31 BITS	Reduced Almanac Packet 4 31 BITS	4 BITS	CRC 24 BITS

Reduced Almanac Packet 2
RESERVED

* MESSAGE TOW COUNT = 17 MSB OF ACTUAL TOW COUNT AT START OF NEXT 6-SECOND MESSAGE

Figure 20-4. *Message type 31 - Clock & Reduced Almanac*
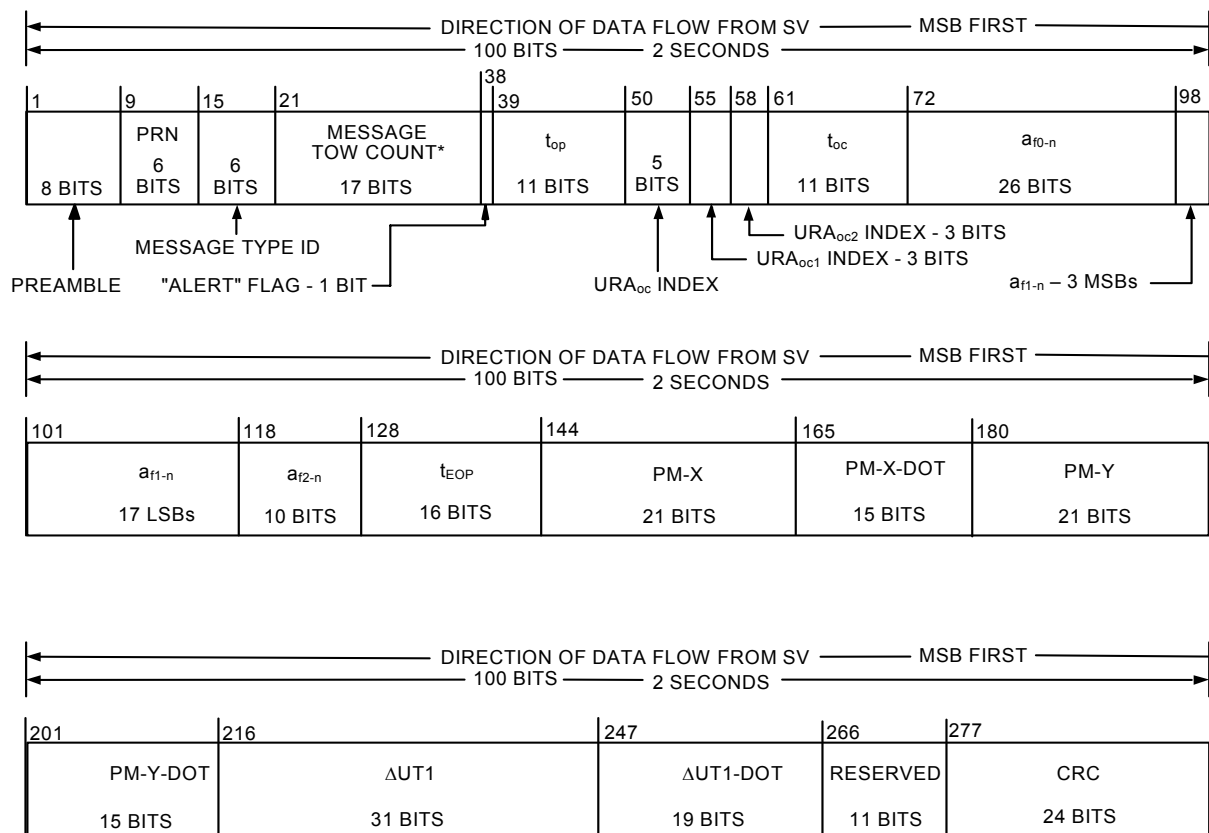
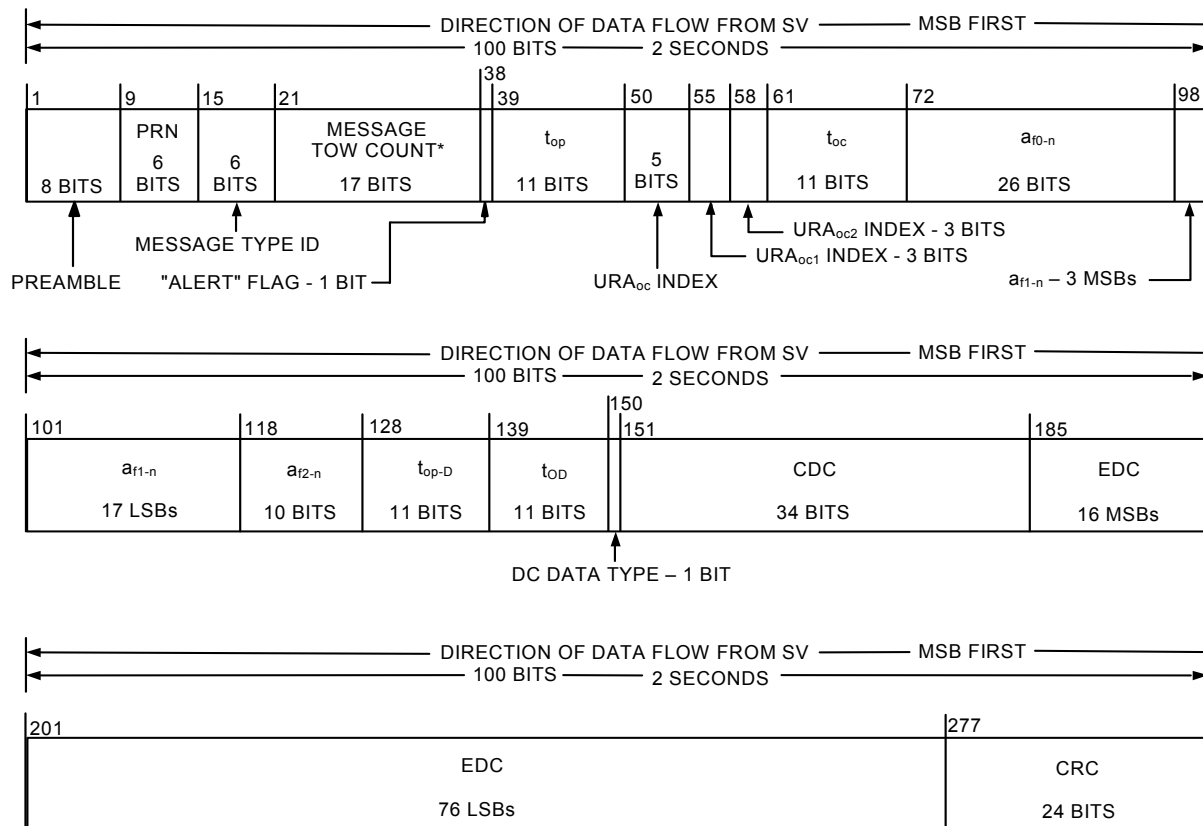Figure 20-5. *Message type 32 - Clock & EOP*
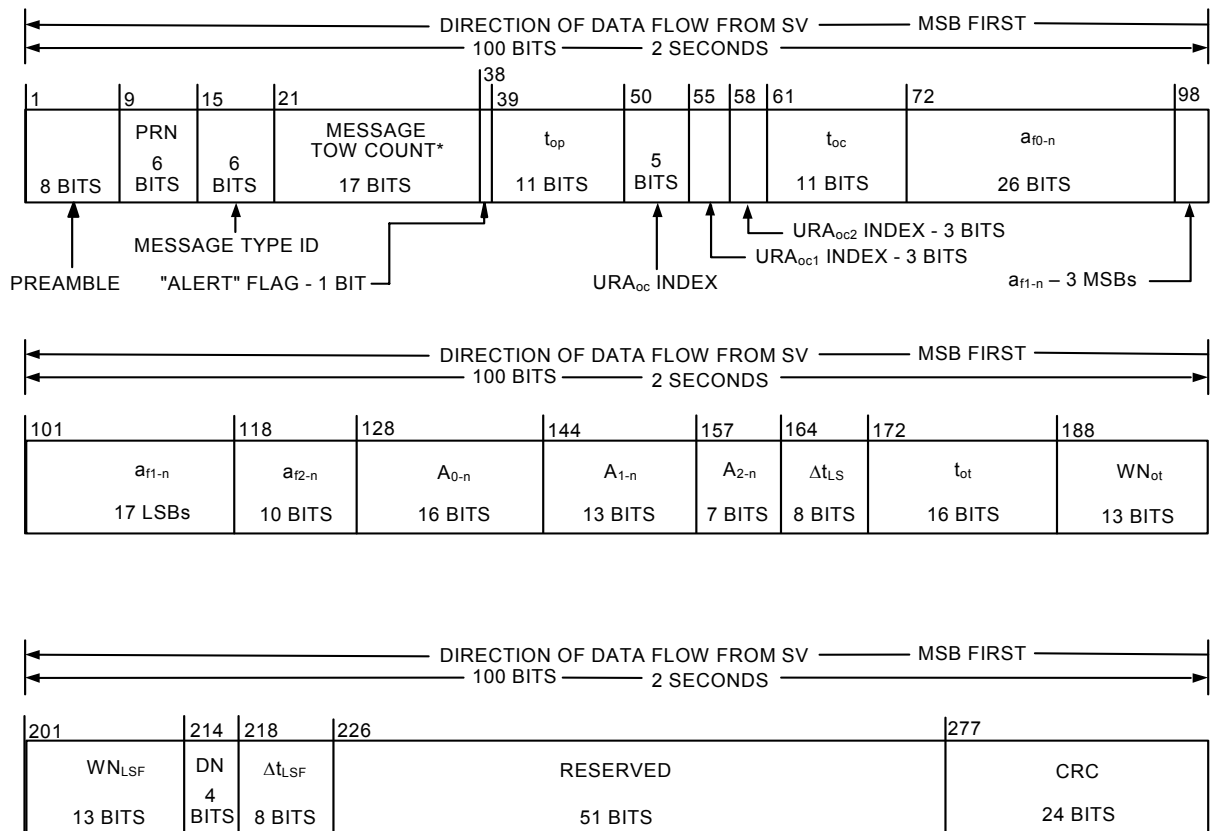
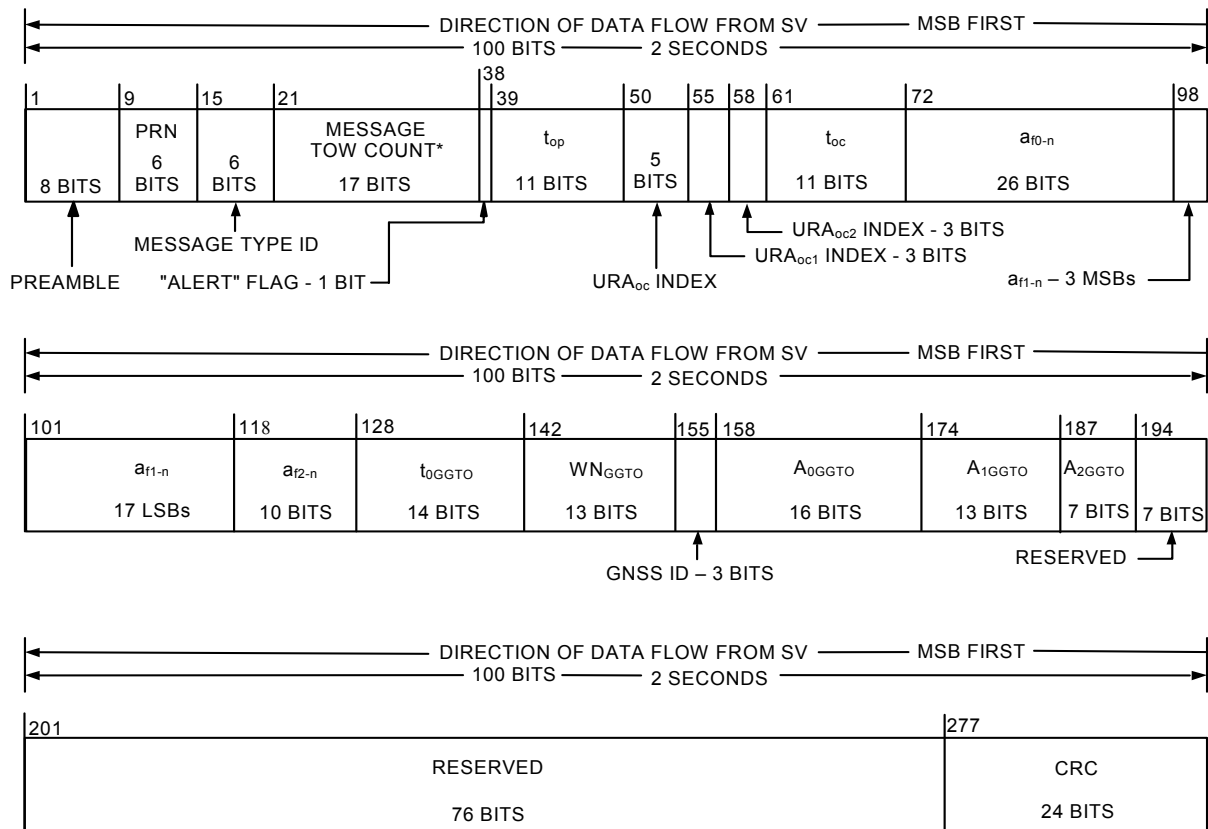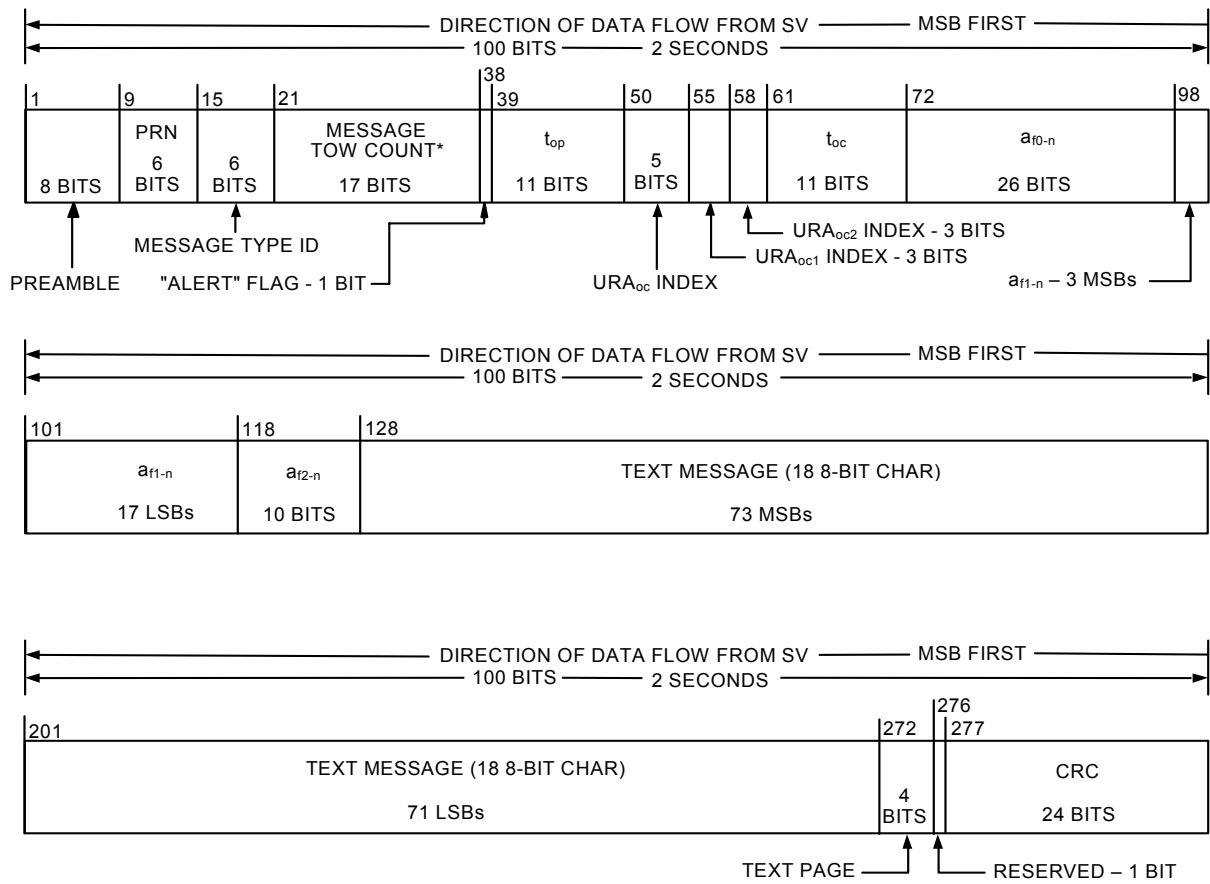* MESSAGE TOW COUNT = 17 MSB OF ACTUAL TOW COUNT AT START OF NEXT 6-SECOND MESSAGE

Figure 20-6. *Message type 33 - Clock & UTC*

DIRECTION OF DATA FLOW FROM SV ——— MSB FIRST ———
——— 100 BITS ——— 2 SECONDS ———

	PRN 6 BITS	6 BITS	MESSAGE TOW COUNT* 17 BITS	t_{op} 11 BITS	5 BITS			t_{oc} 11 BITS	a_{f0-n} 26 BITS	

1 9 15 21 38/39 50 55 58 61 72 98

8 BITS

PREAMBLE

MESSAGE TYPE ID

"ALERT" FLAG - 1 BIT

URA_{oc} INDEX

URA_{oc1} INDEX - 3 BITS

URA_{oc2} INDEX - 3 BITS

a_{f1-n} – 3 MSBs

DIRECTION OF DATA FLOW FROM SV ——— MSB FIRST ———
——— 100 BITS ——— 2 SECONDS ———

a_{f1-n} 17 LSBs	a_{f2-n} 10 BITS	t_{op-D} 11 BITS	t_{OD} 11 BITS		CDC 34 BITS	EDC 16 MSBs

101 118 128 139 150/151 185

DC DATA TYPE – 1 BIT

DIRECTION OF DATA FLOW FROM SV ——— MSB FIRST ———
——— 100 BITS ——— 2 SECONDS ———

EDC 76 LSBs	CRC 24 BITS

201 277

* MESSAGE TOW COUNT = 17 MSB OF ACTUAL TOW COUNT AT START OF NEXT 6-SECOND MESSAGE

CDC = Clock Differential Correction
EDC = Ephemeris Differential Correction

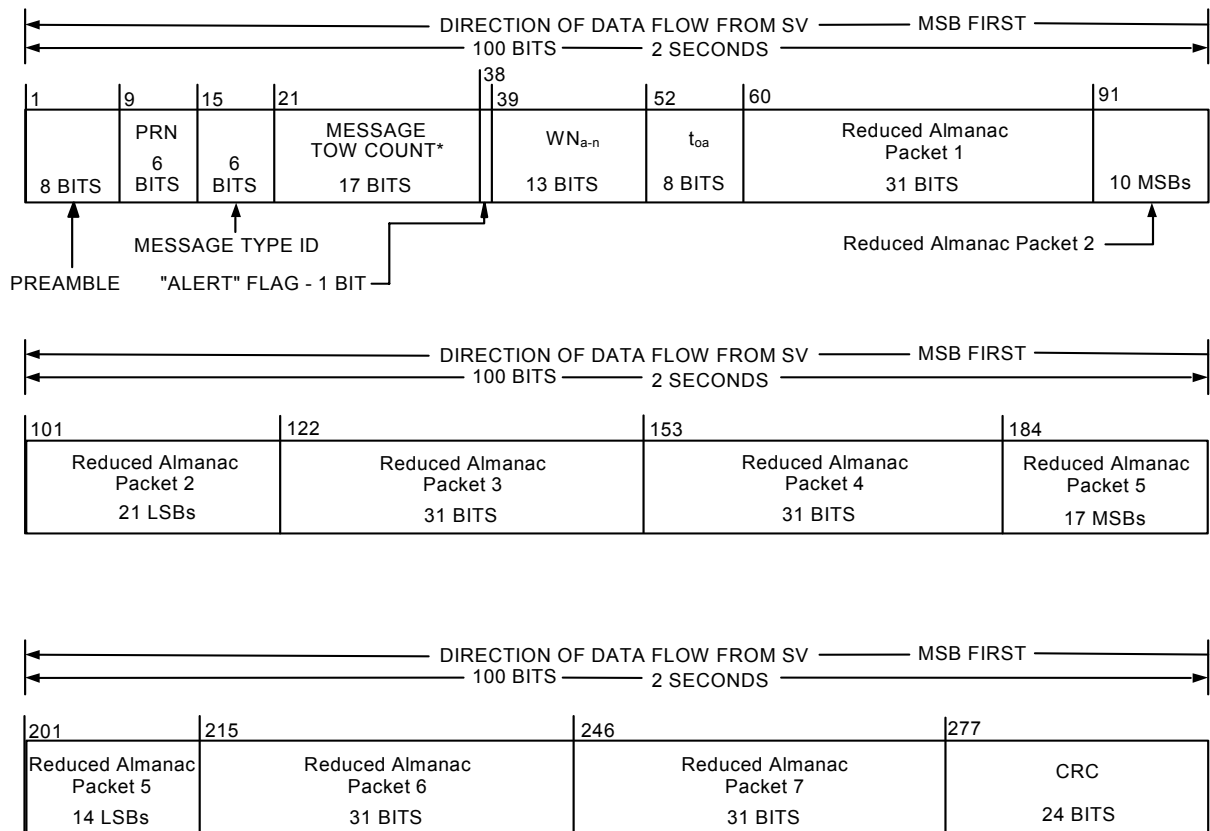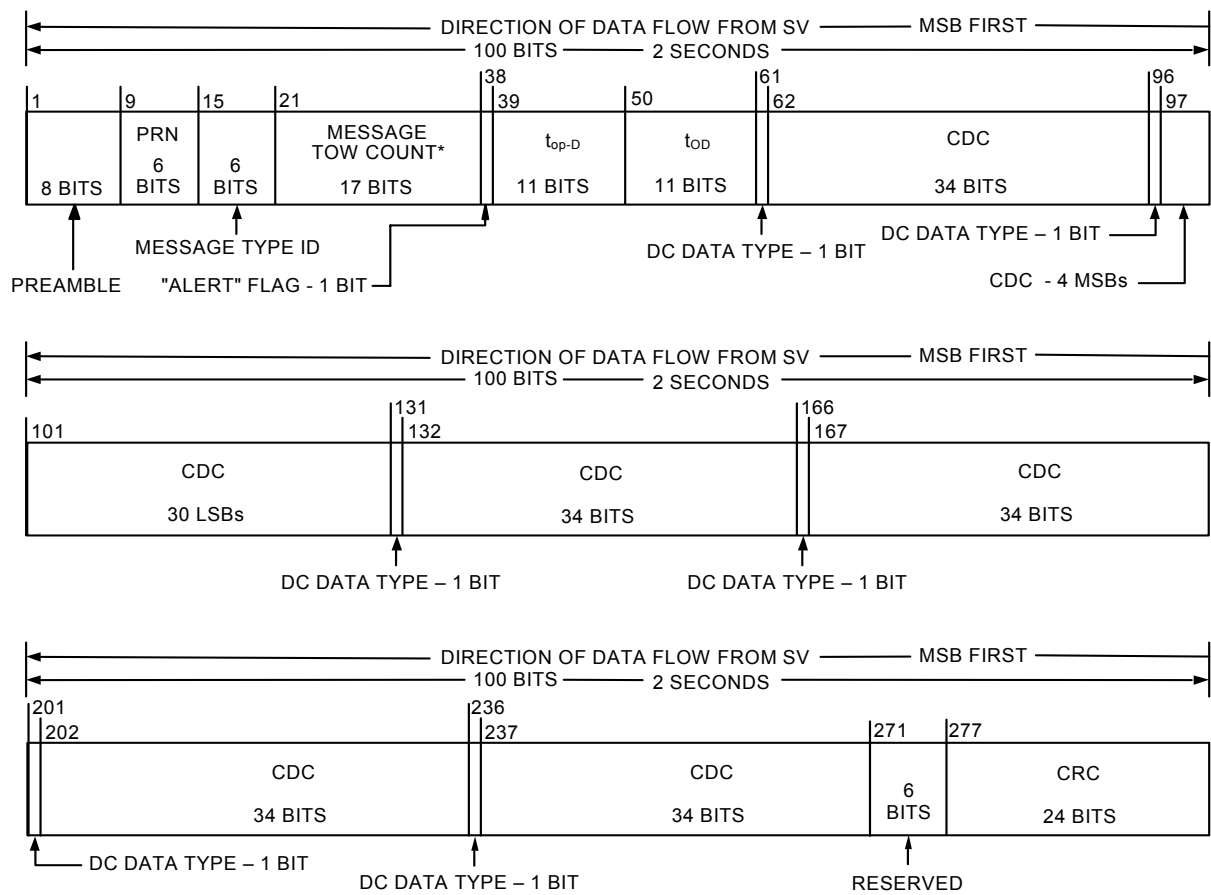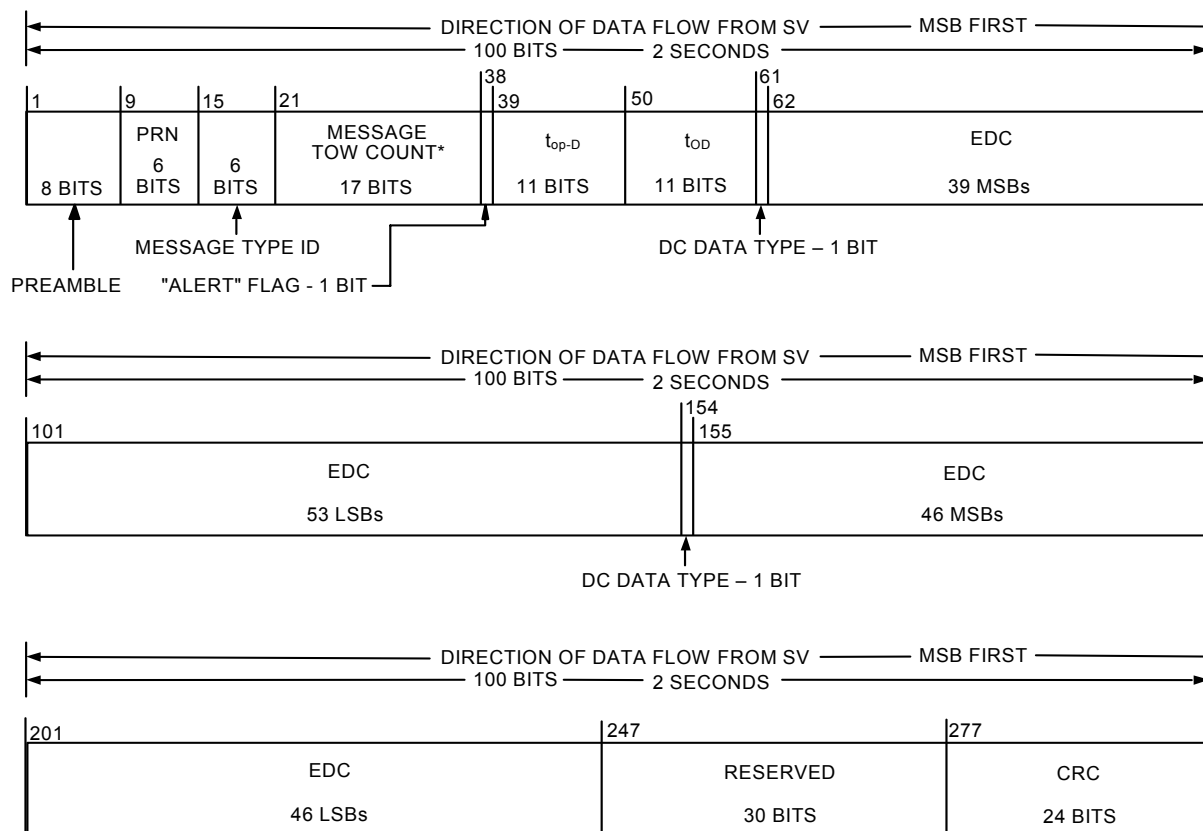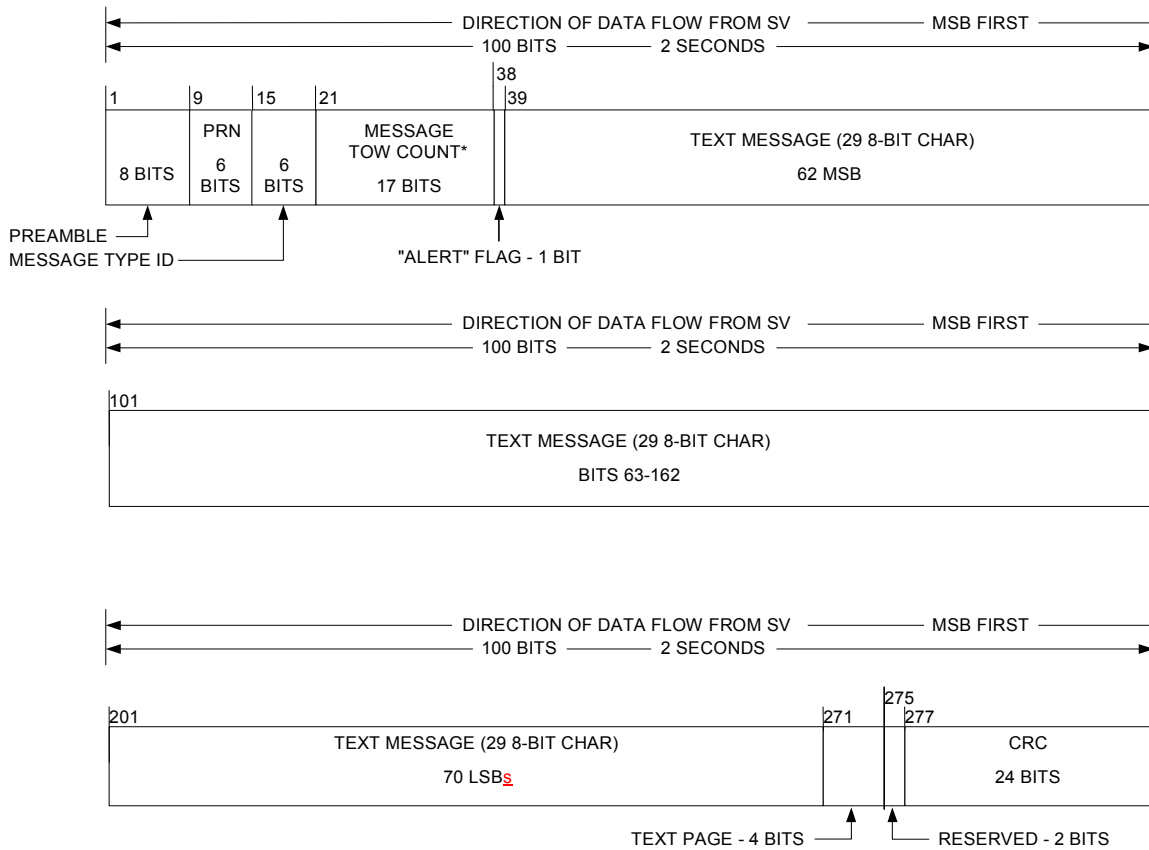*Figure 20-*7. *Message type 34 - Clock & Differential Correction*

Figure 20-8. Message type 35 - Clock & GGTO

Figure 20-9. Message type 36 - Clock & Text

* MESSAGE TOW COUNT = 17 MSBs OF ACTUAL TOW COUNT AT START OF NEXT 6-SECOND MESSAGE

Figure 20-10. Message type 12 -Reduced Almanac

* MESSAGE TOW COUNT = 17 MSBs OF ACTUAL TOW COUNT AT START OF NEXT 6-SECOND MESSAGE

DIRECTION OF DATA FLOW FROM SV ——— MSB FIRST ———
——— 100 BITS ——— 2 SECONDS ———

1 | 9 | 15 | 21 | 38 / 39 | 50 | 61 / 62 | 96 / 97

| 8 BITS | PRN 6 BITS | 6 BITS | MESSAGE TOW COUNT* 17 BITS | t_{op-D} 11 BITS | t_{OD} 11 BITS | CDC 34 BITS |

PREAMBLE
MESSAGE TYPE ID
"ALERT" FLAG - 1 BIT
DC DATA TYPE – 1 BIT
DC DATA TYPE – 1 BIT
CDC - 4 MSBs

DIRECTION OF DATA FLOW FROM SV ——— MSB FIRST ———
——— 100 BITS ——— 2 SECONDS ———

101 | 131 / 132 | 166 / 167

| CDC 30 LSBs | CDC 34 BITS | CDC 34 BITS |

DC DATA TYPE – 1 BIT
DC DATA TYPE – 1 BIT

DIRECTION OF DATA FLOW FROM SV ——— MSB FIRST ———
——— 100 BITS ——— 2 SECONDS ———

201 / 202 | 236 / 237 | 271 | 277

| CDC 34 BITS | CDC 34 BITS | 6 BITS | CRC 24 BITS |

DC DATA TYPE – 1 BIT
DC DATA TYPE – 1 BIT
RESERVED

* MESSAGE TOW COUNT = 17 MSBs OF ACTUAL TOW COUNT AT START OF NEXT 6-SECOND MESSAGE

CDC = Clock Differential Correction

*Figure 20-11. Message type 13 - Clock Differential Correction*

DIRECTION OF DATA FLOW FROM SV ——— MSB FIRST ———
——— 100 BITS ——— 2 SECONDS ———

1	9	15	21		38 39	50	61 62	
8 BITS	PRN 6 BITS	6 BITS	MESSAGE TOW COUNT* 17 BITS		t_{op-D} 11 BITS	t_{OD} 11 BITS		EDC 39 MSBs

PREAMBLE

MESSAGE TYPE ID

"ALERT" FLAG - 1 BIT

DC DATA TYPE – 1 BIT

DIRECTION OF DATA FLOW FROM SV ——— MSB FIRST ———
——— 100 BITS ——— 2 SECONDS ———

101	154 155	
EDC 53 LSBs		EDC 46 MSBs

DC DATA TYPE – 1 BIT

DIRECTION OF DATA FLOW FROM SV ——— MSB FIRST ———
——— 100 BITS ——— 2 SECONDS ———

201	247	277
EDC 46 LSBs	RESERVED 30 BITS	CRC 24 BITS

* MESSAGE TOW COUNT = 17 MSBs OF ACTUAL TOW COUNT AT START OF NEXT 6-SECOND MESSAGE

EDC = Ephemeris Differential Correction

Figure 20-12. Message type 14 - Ephemeris Differential Correction

DIRECTION OF DATA FLOW FROM SV ———— MSB FIRST
———— 100 BITS ———— 2 SECONDS ————

	PRN 6 BITS	6 BITS	MESSAGE TOW COUNT* 17 BITS	TEXT MESSAGE (29 8-BIT CHAR) 62 MSB
8 BITS				

PREAMBLE
MESSAGE TYPE ID
"ALERT" FLAG - 1 BIT

DIRECTION OF DATA FLOW FROM SV ———— MSB FIRST
———— 100 BITS ———— 2 SECONDS ————

TEXT MESSAGE (29 8-BIT CHAR)

BITS 63-162

DIRECTION OF DATA FLOW FROM SV ———— MSB FIRST
———— 100 BITS ———— 2 SECONDS ————

TEXT MESSAGE (29 8-BIT CHAR) 70 LSBs		CRC 24 BITS

TEXT PAGE - 4 BITS ———— RESERVED - 2 BITS

* MESSAGE TOW COUNT = 17 MSBs OF ACTUAL TOW COUNT AT START OF NEXT 6-SECOND MESSAGE

Figure 20-13. Message type 15 - Text
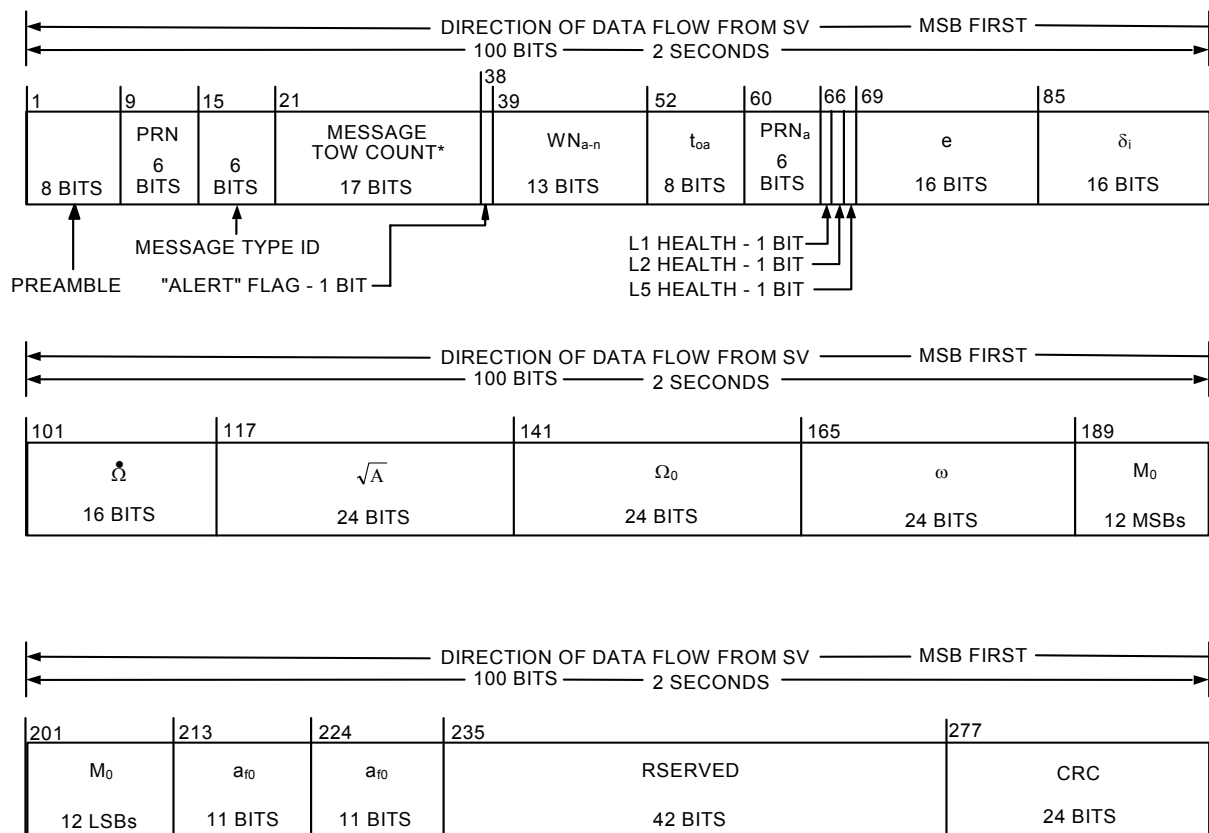
Figure 20-14. Message Type 16 - Almanac

* MESSAGE TOW COUNT = 17 MSBs OF ACTUAL TOW COUNT AT START OF NEXT 6-SECOND MESSAGE

20.3.3.1 Message Types 10 and 11 Ephemeris and Health Parameters.

20.3.3.1.1 Message Types 10 and 11 Ephemeris and Health Parameter Content. *The contents of the SV health, ephemeris representation and accuracy parameters in Message Types 10 and 11 are defined below followed by material pertinent to the use of the data. Message type 10 in conjunction with message type 11, provide users with the requisite data to calculate SV position. The general format of message types 10 and 11 consist of data fields for reference time tags, a set of gravitational harmonic correction terms, rates and rate corrections to quasi-Keplerian elements, and an accuracy indicator for ephemeris-related data.*

The ephemeris parameters in the message type 10 and type 11 describe the orbit of the transmitting SV during the curve fit intervals of three hours. The nominal transmission interval is two hours, and shall coincide with the first two hours of the curve fit interval. The period of applicability for ephemeris data coincides with the entire three-hour curve fit interval. Table 20-I gives the definition of the orbital parameters using terminology typical of Keplerian orbital parameters; it is noted, however, that the transmitted parameter values are expressed such that they provide the best trajectory fit in Earth-Centered, Earth-Fixed (ECEF) coordinates for each specific fit interval. The user shall not interpret intermediate coordinate values as pertaining to any conventional coordinate system.

Any change in the Message Type 10 and 11 ephemeris data will be accomplished with a simultaneous change in the t_{oe} value. The CS will assure that the t_{oe} value, for at least the first data set transmitted by an SV after an upload, is different from that transmitted prior to the cutover. See Section 20.3.4.5 of IS-GPS-200 for additional information regarding t_{oe}.

20.3.3.1.1.1 Transmission Week Number.   Bits 39 through 51 *of message type 10* shall contain 13 bits which are a modulo-8192 binary representation of the current GPS week number at the start of the data set transmission interval (see paragraph 6.2.4 of IS-GPS-200). These 13 bits are comprised of 10 LSBs (WN) that represent the 10 MSBs of the 29-bit Z-count as qualified in paragraph 20.3.3.3.1.1 of IS-GPS-200, and 3 MSBs (WN_e) which are three extra bits to extend the range of transmission week number from 10 bits to 13 bits.

20.3.3.1.1.2 *Signal* Health (L1/L2/L5). The three, one-bit, health indication in bits 52 through 54 *of message type 10* refers to the L1, L2, and L5 signals of the transmitting SV. The health of each signal is indicated by,

        0 = Signal OK,

        1 = Signal bad or unavailable.

The health indication shall be given relative to the "as designed" capabilities of each SV. Accordingly, any SV that does not have a certain capability will be indicated as "healthy" if the lack of this capability is inherent in its design or if it has been configured into a mode that is normal from a user standpoint and does not require that capability.

The predicted health data will be updated at the time of upload when a new data set has been built by the CS. The transmitted health data may not correspond to the actual health of the transmitting SV.

Additional SV health data are given in *the almanac in* Message Types *12, 16,* and *31*. The data given in Message Type 1*0* may differ from that shown in the other *m*essage*s* of the transmitting SV and/or other SVs since the latter may be updated at a different time.

20.3.3.1.1.3 *Data Predict Time of Week.* *Bits 55 through 65 of message type 10 and bits 39 through 49 of message types 30 through 36 shall contain the data predict time of week (t_{op}). The t_{op} term provides the epoch time of week of the state estimate utilized for the prediction of satellite clock parameters- expressed by the transmitted clock correction polynomial terms – and the quasi-Keplerian ephemeris parameters.*

20.3.3.1.1.*4*   <u>SV Accuracy.</u>   Bits *6*6 through *70 of message type 10* shall contain the *ephemeris User Range Accuracy (*URA$_{oe}$*)* index of the SV for the unauthorized (non-Precise Positioning Service) user. The URA$_{oe}$ *shall provide the ephemeris-related user range accuracy index of the SV as a function of the current ephemeris message curve fit interval. While the ephemeris-related URA may vary over the ephemeris message curve fit interval, the URA$_{oe}$ index (N) in message type 10 shall correspond to the maximum URA$_{oe}$ expected over the entire curve fit interval.*

The URA$_{oe}$ index is a signed, two's complement integer in the range of +15 to –16 and has the following relationship to the ephemeris URA:

URA$_{oe}$ Index	URA$_{oe}$ (meters)			
15	6144.00	<	URA$_{oe}$	
14	3072.00	<	URA$_{oe}$ ≤	6144.00
13	1536.00	<	URA$_{oe}$ ≤	3072.00
12	768.00	<	URA$_{oe}$ ≤	1536.00
11	384.00	<	URA$_{oe}$ ≤	768.00
10	192.00	<	URA$_{oe}$ ≤	384.00
9	96.00	<	URA$_{oe}$ ≤	192.00
8	48.00	<	URA$_{oe}$ ≤	96.00
7	24.00	<	URA$_{oe}$ ≤	48.00
6	13.65	<	URA$_{oe}$ ≤	24.00
5	9.65	<	URA$_{oe}$ ≤	13.65
4	6.85	<	URA$_{oe}$ ≤	9.65
3	4.85	<	URA$_{oe}$ ≤	6.85
2	3.40	<	URA$_{oe}$ ≤	4.85
1	2.40	<	URA$_{oe}$ ≤	3.40
0	1.70	<	URA$_{oe}$ ≤	2.40
-1	1.20	<	URA$_{oe}$ ≤	1.70
-2	0.85	<	URA$_{oe}$ ≤	1.20
-3	0.60	<	URA$_{oe}$ ≤	0.85
-4	0.43	<	URA$_{oe}$ ≤	0.60
-5	0.30	<	URA$_{oe}$ ≤	0.43
-6	0.21	<	URA$_{oe}$ ≤	0.30
-7	0.15	<	URA$_{oe}$ ≤	0.21
-8	0.11	<	URA$_{oe}$ ≤	0.15
-9	0.08	<	URA$_{oe}$ ≤	0.11
-10	0.06	<	URA$_{oe}$ ≤	0.08
-11	0.04	<	URA$_{oe}$ ≤	0.06
-12	0.03	<	URA$_{oe}$ ≤	0.04
-13	0.02	<	URA$_{oe}$ ≤	0.03
-14	0.01	<	URA$_{oe}$ ≤	0.02
-15			URA$_{oe}$ ≤	0.01
-16	*No accuracy prediction available—use at own risk*			

20.3.3.*1*.2 <u>Message Type*s* 1*0* and *11* Ephemeris Parameter Characteristics</u>. For each ephemeris parameter contained in Message Types 1*0* and *11*, the number of bits, the scale factor of the *least significant bit (*LSB*)* (which is the last bit received), the range, and the units are as specified in Table 20-*I*. See Figures 20-1 and 20-2 for complete bit allocation in Message Types 1*0* and *11*.

20.3.3.*1*.3 <u>User Algorithm for Determination *of SV Postion*</u>. The user shall compute the ECEF coordinates of position for the *SV's antenna* phase center *(APC)* utilizing a variation of the equations shown in Table 20-*II*. The ephemeris parameters are Keplerian in appearance; the values of these parameters, however, are produced by the CS via a least squares curve fit of the predicted ephemeris of the *SV APC* (time-position quadruples; t, x, y, z expressed in ECEF coordinates).

The sensitivity of the SV's position to small perturbations in most ephemeris parameters is extreme. The sensitivity of position to the parameters A, $C_{rc\text{-}n}$, and $C_{rs\text{-}n}$ is about one meter/meter. The sensitivity of position to the angular parameters is on the order of 10^8 meters/semi-circle, and to the angular rate parameters is on the order of 10^{12} meters/semi-circle/second. Because of this extreme sensitivity to angular perturbations, the value of π used in the curve fit is given here. π is a mathematical constant, the ratio of a circle's circumference to its diameter. Here π is taken as 3.1415926535898.

Parameter		No. of Bits**	Scale Factor (LSB)	Effective Range***	Units
Table 20-I. Messages Type 10 and 11 Parameters (1 of 2)					
Week No.		13	1		weeks
SV accuracy		5*			(see text)
Signal health (L1/L2/L5)		3	1		(see text)
t_{op}	Data predict time of week	11	300	604,500	seconds
ΔA ****	Semi-major axis difference at reference time	26*	2^{-9}		meters
A-DOT	Change rate in semi-major axis	25*	2^{-21}		meters/sec
Δn_0	Mean Motion difference from computed value at reference time	17*	2^{-44}		semi-circles/sec
Δn_0-DOT	Rate of mean motion difference from computed value	23*	2^{-57}		semi-circles/sec^2
M_{0-n}	Mean anomaly at reference time	33*	2^{-32}		semi-circles
e_n	Eccentricity	33*	2^{-34}	0.03	dimensionless
$_n$	Argument of perigee	33*	2^{-32}		semi-circles

*   Parameters so indicated are two's complement, with the sign bit (+ or -) occupying the MSB;
**   See Figure 20-1 for complete bit allocation in Message Type 10;
***   Unless otherwise indicated in this column, effective range is the maximum range attainable with indicated bit allocation and scale factor.
****   Relative to A_{REF} = 26,559,710 meters.

Table 20-I.   Message Type 10 and 11 Parameters (2 of 2)

	Parameter	No. of Bits**	Scale Factor (LSB)	Effective Range***	Units
t_{oe}	Ephemeris data reference time of week	11	300	604,500	seconds
Ω_{0-n}****	Reference right ascension angle	33*	2^{-32}		semi-circles
$\Delta\Omega\text{-}DOT$ *****	Rate of right ascension difference	17*	2^{-44}		semi-circles/sec
i_{0-n}	Inclination angle at reference time	33*	2^{-32}		semi-circles
$i_{0-n}\text{ }\text{–}DOT$	Rate of inclination angle	15*	2^{-44}		semi-circles/sec
C_{is-n}	Amplitude of the sine harmonic correction term to the angle of inclination	16*	2^{-30}		radians
C_{ic-n}	Amplitude of the cosine harmonic correction term to the angle of inclination	16*	2^{-30}		radians
C_{rs-n}	Amplitude of the sine correction term to the orbit radius	24*	2^{-8}		meters
C_{rc-n}	Amplitude of the cosine correction term to the orbit radius	24*	2^{-8}		meters
C_{us-n}	Amplitude of the sine harmonic correction term to the argument of latitude	21*	2^{-30}		radians
C_{uc-n}	Amplitude of the sine harmonic correction term to the argument of latitude	21*	2^{-30}		radians

* Parameters so indicated are two's complement, with the sign bit (+ or -) occupying the MSB;

** See Figure 20-1 and Figure 20-2 for complete bit allocation in Message Types 10 and 11;

*** Unless otherwise indicated in this column, effective range is the maximum range attainable with indicated bit allocation and scale factor.

**** Ω_{0-n} is the right ascension angle at the weekly epoch (Ω_{0-w}) propagated to the reference time at the rate of right ascension {$\Omega\text{-}DOT_{REF}$ Table 20-II}.

***** Relative to $\Omega\text{-}DOT_{REF}$ = -2.6 x 10^{-9} semi-circles/second.

Table 20-II. Elements of Coordinate System (part 1 of 2)	
Element/Equation	**Description**
$\mu = 3.986005 \times 10^{14}$ meters^3/sec^2	WGS 84 value of the earth's gravitational constant for GPS user
$\Omega_e\text{-DOT} = 7.2921151467 \times 10^{-5}$ rad/sec	WGS 84 value of the earth's rotation rate
$A_0 = A_{REF} + \Delta A$ *	Semi-Major Axis at reference time
$A_k = A_0 + (A\text{-DOT})\, t_k$	Semi-Major Axis
$n_0 = \sqrt{\dfrac{\mu}{A_0{}^3}}$	Computed Mean Motion (rad/sec)
$t_k = t - t_{oe}$ **	Time from ephemeris reference time
$\Delta n_A = \Delta n_0 + \tfrac{1}{2}\,(\Delta\, n_0\text{-DOT})\, t_k$	Mean motion difference from computed value
$n_A = n_0 + \Delta n_A$	Corrected Mean Motion
$M_k = M_0 + n_A\, t_k$	Mean Anomaly
$M_k = E_k - e_n \sin E_k$	Kepler's equation for Eccentric Anomaly (radians) (may be solved by iteration)
$v_k = \tan^{-1}\left\{\dfrac{\sin v_k}{\cos v_k}\right\}$	True Anomaly
$= \tan^{-1}\left\{\dfrac{\sqrt{1-e^2}\,\sin E_k\,/\,(1-e\cos E_k)}{(\cos E_k - e)\,/\,(1-e\cos E_k)}\right\}$	
$E_k = \cos^{-1}\left\{\dfrac{e + \cos v_k}{1 + e\cos v_k}\right\}$	Eccentric Anomaly

* $A_{REF} = 26,559,710$ meters

**   *t* is GPS system time at time of transmission, i.e., GPS time corrected for transit time (range/speed of light). Furthermore, t_k shall be the actual total difference between the time *t* and the epoch time t_{oe}, and must account for beginning or end of week crossovers. That is if t_k is greater than 302,400 seconds, subtract 604,800 seconds from t_k. If t_k is less than -302,400 seconds, add 604,800 seconds to t_k.

Table 20-II.   Elements of Coordinate System (part 2 of 2)

Element/Equation *	Description
$\Phi_k = \nu_k + \omega_n$	Argument of Latitude
$\delta u_k = C_{us\text{-}n} sin2\Phi_k + C_{uc\text{-}n} cos2\Phi_k$	Argument of Latitude Correction
$\delta r_k = C_{rs\text{-}n} sin2\Phi_k + C_{rc\text{-}n} cos2\Phi_k$	Radial Correction
$\delta i_k = C_{is\text{-}n} sin2\Phi_k + C_{ic\text{-}n} cos2\Phi_k$	Inclination Correction
	Second Harmonic Perturbations
$u_k = \Phi_k + \delta u_k$	Corrected Argument of Latitude
$r_k = A_k(1 - e\ cos\ E_k) + \delta r_k$	Corrected Radius
$i_k = i_{o\text{-}n} + (i_{o\text{-}n}\text{-}DOT)t_k + \delta i_k$	Corrected Inclination
$x_k' = r_k\ cos\ u_k$	
$y_k' = r_k\ sin\ u_k$	Positions in orbital plane
$\Omega\text{-}DOT = \Omega\text{-}DOT_{REF} + \Delta\Omega\text{-}DOT$ ***	Rate of Right Ascension
$\Omega_k = \Omega_{0\text{-}n} + (\ \Omega\text{-}DOT - \Omega_e\text{-}DOT\ )\ t_k - \Omega_e\text{-}DOT\ t_{oe}$	Corrected Longitude of Ascending Node
$x_k = x_k'\ cos\ \Omega_k - y_k'\ cos\ i_k\ sin\ \Omega_k$	
$y_k = x_k'\ sin\ \Omega_k + y_k'\ cos\ i_k\ cos\ \Omega_k$	Earth-fixed coordinates of SV antenna phase center
$z_k = y_k'\ sin\ i_k$	

*** $\Omega\text{-}DOT_{REF} = -2.6\ x\ 10^{-9}$ semi-circles/second.

20.3.3.*2* Message Type*s 30 through 36 SV* Clock *Correction* Parameters.

20.3.3.*2*.1 <u>Message Type*s 30 through 36 SV* Clock *Correction* Parameter Content.</u> The clock parameters in *any one of* Message Type*s 30 through 36* describe the SV time scale during the period of validity. The *clock* parameters in a data set shall be valid during the interval of time in which they are transmitted and shall remain valid for an additional period of time after transmission of the next data set has started. *The timing information for the messages is described in section 20.3.4.*

The general format of Message Types 30 through 36 includes data fields for SV clock correction coefficients. Any one of Message types 30 through 36 in conjunction with message types 10 and 11 provide users with the requisite data to correct SV time and to calculate SV position precisely.

20.3.3.*2*.1.1 <u>SV Clock Correction</u>. *Any one of m*essage Type*s 30 through 36, Figure 20-3 through Figure 20-9,* contains the parameters needed by the users for apparent SV clock correction. *Bits 61 to 71 contain t_{oc}, clock data reference time of week. Bits 72 to 127 contain SV clock correction coefficients.* The related algorithm is given in paragraph 20.3.3.*2*.3.

20.3.3.2.1.2 <u>Data Predict Time of Week</u>. *Bits 55 through 65 of message types 30 through 36 shall contain the data predict time of week (t_{op}). The t_{op} term provides the epoch time of week of the state estimate utilized for the prediction of SV clock correction coefficients.*

20.3.3.*2*.2 <u>Clock Parameter Charateristics</u>. The number of bits, the scale factors of the LSB (which is the last bit received), the range, and the units of *clock correction parameters* shall be as specified in Table 20-*III*.

20.3.3.*2*.3 <u>User Algorithms for *SV* Clock *Correction* Data</u>. The algorithms defined in paragraph 20.3.3.3.3.1 of I*S*-GPS-200 allow all users to correct the code phase time received from the SV with respect to both SV code phase offset and relativistic effects. However, since the SV clock corrections of equations in paragraph 20.3.3.3.3.1 of I*S*-GPS-200 are estimated by the CS using dual frequency L1 and L2 P(Y) code measurements, the single-frequency L5 user and the dual-frequency L1 and L5, and L2 and L5 users must apply additional terms to the SV clock corrections equations. These terms are described in paragraph 20.3.3.3.*1*.

Parameter		No. of Bits**	Scale Factor (LSB)	Effective Range***	Units
t_{oc}	*Clock Data Reference Time of Week*	*11*	*300*	*604,500*	seconds
URA$_{oc}$ Index	*SV Clock Accuracy Index*	*5**			*(see text)*
URA$_{oc1}$ Index	*SV Clock Accuracy Change Index*	*3*			*(see text)*
URA$_{oc2}$ Index	*SV Clock Accuracy Change Rate Index*	*3*			*(see text)*
$a_{f2\text{-}n}$	*SV Clock Drift Rate Correction Coefficient*	*10**	2^{-60}		sec/sec^2
$a_{f1\text{-}n}$	*SV Clock Drift Correction Coefficient*	*20**	2^{-48}		sec/sec
$a_{f0\text{-}n}$	*SV Clock Bias Correction Coefficient*	*26**	2^{-35}		seconds

Table 20-*III.*   Clock *Correction* and Accuracy Parameters

*   Parameters so indicated are two's complement, with the sign bit (+ or -) occupying the MSB;
**   See Figure 20-*3 through 30-9* for complete bit allocation in message types *30 to 36*;
***   Unless otherwise indicated in this column, effective range is the maximum range attainable with indicated bit allocation and scale factor.

20.3.3.2.4 SV Clock Accuracy Estimates. Bits 50 through 54, and 55 through 57, and 58 through 60 of message types 30 through 36 shall contain the URA_{oc} Index, URA_{oc1} Index, and URA_{oc2} Index, respectively, of the SV (reference paragraph 6.2.1) for the unauthorized user. The URA_{oc} Index together with URA_{oc1} Index and URA_{oc2} Index shall give the clock-related user range accuracy of the SV as a function of time since the prediction (t_{op}) used to generate the uploaded clock correction polynomial terms.

The user shall calculate the clock-related URA with the equation (in meters);

$$URA_{oc} = URA_{ocb} + URA_{oc1}\,(t - t_{op}) \qquad \text{for } t - t_{op} \leq 93{,}600 \text{ seconds}$$

$$URA_{oc} = URA_{ocb} + URA_{oc1}\,(t - t_{op}) + URA_{oc2}\,(t - t_{op} - 93{,}600)^2 \qquad \text{for } t - t_{op} > 93{,}600 \text{ seconds}$$

where

t = GPS time (must account for beginning or end of week crossovers),

t_{op} = time of week of the state estimate utilized for the prediction of satellite clock correction parameters.

The CS shall derive URA_{ocb} at time t_{op} which, when used together with URA_{oc1} and URA_{oc2} in the above equations, results in the minimum URA_{oc} that is greater than the predicted URA_{oc} during the entire duration up to 14 days after t_{op}.

The user shall use the broadcast URA_{oc} Index to derive URA_{ocb}. The index is a signed, two's complement integer in the range of +15 to –16 and has the following relationship to the clock-related user derived URA_{ocb}:

URA_{oc} Index	URA_{ocb} (meters)			
15	6144.00	$<$	URA_{ocb}	
14	3072.00	$<$	$URA_{ocb} \leq$	6144.00
13	1536.00	$<$	$URA_{ocb} \leq$	3072.00
12	768.00	$<$	$URA_{ocb} \leq$	1536.00
11	384.00	$<$	$URA_{ocb} \leq$	768.00
10	192.00	$<$	$URA_{ocb} \leq$	384.00
9	96.00	$<$	$URA_{ocb} \leq$	192.00
8	48.00	$<$	$URA_{ocb} \leq$	96.00
7	24.00	$<$	$URA_{ocb} \leq$	48.00
6	13.65	$<$	$URA_{ocb} \leq$	24.00
5	9.65	$<$	$URA_{ocb} \leq$	13.65
4	6.85	$<$	$URA_{ocb} \leq$	9.65
3	4.85	$<$	$URA_{ocb} \leq$	6.85
2	3.40	$<$	$URA_{ocb} \leq$	4.85
1	2.40	$<$	$URA_{ocb} \leq$	3.40
0	1.70	$<$	$URA_{ocb} \leq$	2.40
-1	1.20	$<$	$URA_{ocb} \leq$	1.70
-2	0.85	$<$	$URA_{ocb} \leq$	1.20
-3	0.60	$<$	$URA_{ocb} \leq$	0.85
-4	0.43	$<$	$URA_{ocb} \leq$	0.60
-5	0.30	$<$	$URA_{ocb} \leq$	0.43
-6	0.21	$<$	$URA_{ocb} \leq$	0.30
-7	0.15	$<$	$URA_{ocb} \leq$	0.21
-8	0.11	$<$	$URA_{ocb} \leq$	0.15
-9	0.08	$<$	$URA_{ocb} \leq$	0.11
-10	0.06	$<$	$URA_{ocb} \leq$	0.08
-11	0.04	$<$	$URA_{ocb} \leq$	0.06
-12	0.03	$<$	$URA_{ocb} \leq$	0.04
-13	0.02	$<$	$URA_{ocb} \leq$	0.03
-14	0.01	$<$	$URA_{ocb} \leq$	0.02
-15			$URA_{ocb} \leq$	0.01
-16	*No accuracy prediction available—use at own risk*			

The user may use the upper bound value in the URA_{ocb} range corresponding to the broadcast index, thereby calculating the maximum URA_{oc} that is equal to or greater than the CS predicted URA_{oc}, or the user may use the lower bound value in the range which will provide the minimum URA_{oc} that is equal to or less than the CS predicted URA_{oc}.

The transmitted URA_{oc1} Index is an integer value in the range 0 to 7. URA_{oc1} Index has the following relationship to the URA_{oc1}:

$$URA_{oc1} = \frac{1}{2^N} \text{ (meters/second)}$$

where

$$N = 4 + URA_{oc1} \text{ Index}$$

The transmitted URA_{oc2} Index is an integer value in the range 0 to 7. URA_{oc2} Index has the following relationship to the URA_{oc2}.

$$URA_{oc2} = \frac{1}{2^N} \text{ (meters/second)}$$

where

$$N = 25 + URA_{oc2} \text{ Index}$$

20.3.3.3 Message Type 3*0 Ionospheric and Group Delay Correction* Parameters.

20.3.3.3.1 Message Type 3*0 Ionospheric and Group Delay Correction* Parameter Content. Message type 3*0 provides SV clock correction parameters (ref. Section 20.3.3.2) and* ionospheric *and group delay correction* parameters. *Bits 128 through 192 of message type 30 provide the group delay differential correction terms for L1, L2, L5 signal users. Bits 193 through 256 provide the ionospheric correction parameters for single frequency user. The following algorithms shall apply when interpreting the correction parameters in the message.*

20.3.3.3.1.*1* Estimated L1-L2 Group Delay Differential. The group delay differential correction terms, T_{GD}, $ISC_{L1C/A}$, ISC_{L2C} are contained in bits *128* through *166* of message type 3*0*. See paragraph 30.3.3.3.1.*1* of I*S*-GPS-200. *The bit length, scale factors, ranges, and units of these parameters are given in Table 20-IV.* These group delay differential correction terms are also used for the benefit of single frequency L5-I5 and L5-Q5 users and dual frequency L1/L5 and L2/L5 users.

20.3.3.3.*1.1.1* L1/L2 Inter-Signal Group Delay Differential Correction. See paragraph 30.3.3.3.*1.1.1* of I*S*-GPS-200.

20.3.3.3.1.*2* Estimated L5 Group Delay Differential. The group delay differential correction terms, T_{GD}, ISC_{L5I5} and ISC_{L5Q5}, for the benefit of single frequency L5-I5 and L5-Q5 users and dual frequency L1/L5 and L2/L5 users are contained in bits *128 through 140 and 167 through 192* of Message Type 3*0* (see Figure 20-3 for complete bit allocation). The bit length, scale factors, ranges, and units of these parameters are given in Table 20-*IV.* The bit string of "10000000*00000*" shall indicate that the group delay value is not available. The related algorithms are given in paragraphs 20.3.3.3.*1*.2.*1*, 20.3.3.3.*1*.2.*2*, and 20.3.3.3.*1*.2.*3*.

Parameter	No. of Bits**	Scale Factor (LSB)	Effective Range***	Units
Table 20-*IV*. Group Delay Differential Parameters ****				
T_{GD}	*13**	2^{-35}		seconds
$ISC_{L1C/A}$	*13**	2^{-35}		seconds
ISC_{L2C}	*13**	2^{-35}		seconds
ISC_{L5I5}	*13**	2^{-35}		seconds
ISC_{L5Q5}	*13**	2^{-35}		seconds

*   Parameters so indicated are two's complement with the sign bit (+ or -) occupying the MSB;
**   See Figure 20-3 for complete bit allocation in Message Type 3*0*;
***   Effective range is the maximum range attainable with indicated bit allocation and scale factor;
**** The bit string of "10000000*00000*" will indicate that the group delay value is not available.

20.3.3.3.*1*.2.*1* <u>L1/L5 Inter-Signal Group Delay Differential Correction</u>. The L5 correction terms, T_{GD}, ISC_{L5I5} and ISC_{L5Q5} are provided by the CS to account for the effect of SV group delay differential between *L1 P(Y) and L2 P(Y),* L1 P(Y) and L5 I5*,* and between L1 P(Y) and L5 Q5, respectively. These values are *initially* based on measurements made by the SV contractor during SV manufacture. The values of T_{GD} *and* ISC's for each SV may be subsequently updated to reflect the actual on-orbit group delay differential. For maximum accuracy, the single frequency L5 I5 user must use the correction terms to make further modifications to the code phase offset *in paragraph 20.3.3.3.3.1 of IS-GPS-200 with the equation*:

$$(\Delta t_{SV})_{L5I5} = \Delta t_{SV} - T_{GD} + ISC_{L5I5}$$

where, T_{GD} (see paragraph 20.3.3.3.3.2 of I*S*-GPS-200) and ISC_{L5I5} (described in paragraph *20.3.3.3.1.2*) are provided to the user as Message Type 3*0* data. For maximum accuracy, the single frequency L5 Q5 user must use the correction terms to make further modifications to the code phase offset given by:

$$(\Delta t_{SV})_{L5Q5} = \Delta t_{SV} - T_{GD} + ISC_{L5Q5}$$

where, ISC_{L5Q5} (described in paragraph *20.3.3.3.1.2*) is provided to the user as Message Type 3*0* data.

The values of ISC_{L5I5} and ISC_{L5Q5} are measured values that represent the mean SV group delay differential between the L1 P(Y)-code and the L5 I5-code or L5 Q5-code respectively as follows.

$$ISC_{L5I5} = t_{L1P(Y)} - t_{L5I5}$$
$$ISC_{L5Q5} = t_{L1P(Y)} - t_{L5Q5}$$

where t_{Lix} is the GPS time the ith frequency x signal *(a specific epoch of the signal)* is transmitted from the SV *antenna phase center*.

20.3.3.3.*1.2.2* <u>L1/L5 Ionospheric Correction</u>. The two frequency (L1 C/A and L5 I5) user shall correct for the group delay *and* ionospheric effects by applying the relationship:

$$PR = \frac{PR_{L5I5} - \gamma_{15}PR_{L1C/A} + c(ISC_{L5I5} - \gamma_{15}ISC_{L1C/A})}{1 - \gamma_{15}} - cT_{GD}$$

The two frequency (L1 C/A and L5 Q5) user shall correct for the group delay *and* ionospheric effects by applying the relationship:

$$PR = \frac{PR_{L5Q5} - \gamma_{15}PR_{L1C/A} + c(ISC_{L5Q5} - \gamma_{15}ISC_{L1C/A})}{1 - \gamma_{15}} - cT_{GD}$$

where

    PR = pseudorange corrected for ionospheric effects,

    PR_i = pseudorange measured on the L-band channel indicated by the subscript;

    ISC_i = inter-signal correction for the channel indicated by the subscript (see paragraph *20.3.3.3.1.2*),

    T_{GD} = see paragraph 20.3.3.3.3.2 of I*S*-GPS-200,

    c   = speed of light (see paragraph *20.3.4.3*),

and where, denoting the nominal center frequencies of L1 and L5 as f_{L1} and f_{L5} respectively.

    $\gamma_{15} = (f_{L1}/f_{L5})^2 = (1575.42/1176.45)^2 = (154/115)^2$.

20.3.3.3.*1.2.3* <u>L2/L5 Ionospheric Correction.</u> The two frequency (L2 *C* and L5 I5) user shall correct for the group delay *and* ionospheric effects by applying the relationship:

$$PR = \frac{PR_{L5I5} - \gamma_{25}PR_{L2C} + c(ISC_{L5I5} - \gamma_{25}ISC_{L2C})}{1 - \gamma_{25}} - cT_{GD}$$

The two frequency (L2 C and L5 Q5) user shall correct for the group delay *and* ionospheric effects by applying the relationship:

$$PR = \frac{PR_{L5Q5} - \gamma_{25}PR_{L2C} + c(ISC_{L5Q5} - \gamma_{25}ISC_{L2C})}{1 - \gamma_{25}} - cT_{GD}$$

where

PR =   pseudorange corrected for ionospheric effects,

PR_i =   pseudorange measured on the L-band channel indicated by the subscript,

ISC_i =   inter-signal correction for the channel indicated by the subscript (see paragraph *20.3.3.3.1.2*),

T_{GD} =   see paragraph 20.3.3.3.3.2 of I*S*-GPS-200,

c   =   speed of light (see paragraph *20.3.4.3*).

and where, denoting the nominal center frequencies of L2 and L5 as f_{L2} and f_{L5} respectively.

$$\gamma_{25} = (f_{L2}/f_{L5})^2 = (1227.6/1176.45)^2 = (24/23)^2$$

20.3.3.3.1.*3* <u>Ionospheric Data.</u> The ionospheric parameters which allow the "L5 only" user to utilize the ionospheric model for computation of the ionospheric delay are contained in Message Type 3*0*. The "one frequency" user should use the model given in Figure 20-4 of I*S*-GPS-200 to make this correction. The calculated value of T_{iono} *in the model* is referred to the L1 frequency; if the user is operating on the L5 frequency, the correction term must be multiplied by γ_{15} (reference paragraph 20.3.3.3.*1.2.2*). It is estimated that the use of this model will provide at least a 50 percent reduction in the single-frequency user's RMS error due to ionospheric propagation effects. The bit lengths, scale factors, ranges, and units of these parameters are given in Table 20-X of I*S*-GPS-200 (See Figure 20-3 for complete ionospheric bit allocation).

The ionospheric data shall be updated by the CS at least once every six days while the CS is able to upload the SVs. If the CS is unable to upload the SVs, the ionospheric data transmitted by the SVs may not be accurate. During extended operations *or in the Autonav mode*, if the CS is unable to upload the SVs, the use of this model will yield unpredictable results.

20.3.3.3.*1.4* Example Application of Correction Parameters. A typical system application of the correction parameters for a user receiver is shown in Figure 20-*15*. The ionospheric model referred to in Figure 20-*15* is discussed in paragraph 20.3.3.3.*1.3*.

Figure 20-*15* Sample Application of Correction Parameters

20.3.3.4 <u>Message Type*s 31, 12 and 16* Almanac Parameters</u>. The ~~contents of Message Type 4~~ *almanac parameters are provided in message type 16. The reduced almanac parameters are provided in either message type 31 or type 12. The SV shall broadcast both Message Types 31 (and/or 12) and 16. However, the reduced almanac parameters (i.e. Message Types 31 and/or 12) for the complete set of SVs in the constellation will be broadcast by a SV using shorter duration of time compare to the broadcast of the complete set of full almanac parameters (i.e. Message Type 16). The parameters* are defined below, followed by material pertinent to the use of the data.

20.3.3.4.*1* <u>Almanac Reference Week</u>. Bits *39* through 5*1* of Message Type*s 12 and 16, and bits 128 through 140 of Message Type 31* shall indicate the number of the week (WN$_{a-n}$) to which the almanac reference time (t$_{oa}$) is referenced (see paragraph 20.3.3.4.*2*). The WN$_{a-n}$ term consists of *13* bits which shall be a modulo-*8192* binary representation of the GPS week number (see paragraph 6.2.4) to which the t$_{oa}$ is referenced. Bits *52* through *59* of Message Type*s 12 and 16, and bits 141 to 148 of message type 31* shall contain the value of t$_{oa}$, which is referenced to this WN$_{a-n}$.

20.3.3.4.2 <u>Almanac Reference Time</u>. See paragraph 20.3.3.5.2.2 of I*S*-GPS-200.

20.3.3.4.*3* <u>SV PRN Number</u>. Bits *60* through *65* of Message Type *16 and bits 1 through 6 in each packet of reduced almanac* shall specify PRN number of the SV whose almanac *or reduced almanac, respectively,* is provided in the message *or in the packet*.

20.3.3.4.*4* <u>*Signal* Health</u> *(L1/L2/L5)*. *The three, one-bit, health indication in bits 66, 67 and 68 of Message Type 16 and bits 29,30 and 31 of each packet of reduced almanac refers to the L1, L2, and L5 signals of the SV whose PRN number is specified in the message or in the packet. For each health indicator, a "0" signifies that all NAV data are okay and "1" signifies that some or all NAV data are bad*. The predicted health data will be updated at the time of upload when a new reduced almanac has been built by the CS. The transmitted health data may not correspond to the actual health of the transmitting SV or other SVs in the constellation.

20.3.3.4.*5* <u>Almanac Parameter Content</u>. Message Type *16, Figure 20-14, provides almanac data for a SV whose PRN number is specified in the message.* The almanac data are a reduced-precision subset of the clock and ephemeris parameters. The number of bits, the scale factor (LSB), the range, and the units of the almanac parameters are given in Table 20-VI of I*S*-GPS-200. The user algorithm is essentially the same as the user algorithm used for computing the precise ephemeris *as specified in Table 20-IV of IS-GPS-200. Other parameters appearing in the equations of Table 20-IV, but not provided by the almanac with the reference values, are set to zero for SV position determination.* See paragraph 20.3.3.5.2.3 of I*S*-GPS-200 *for almanac time parameters.*

20.3.3.4.6 Reduced Almanac Parameter Content. Message type 31, Figure 20-4, provides SV clock correction parameters (ref. Section 20.3.3.2) and reduced almanac data packets for 4 SVs. Message type 12, Figure 20-10 contains reduced almanac data packets for 7 SVs.

20.3.3.4.*6*.1 *Reduced* Almanac Data. Message Type*s 31 or 12* contains *reduced* almanac data and SV health words for SVs in the constellation. The *reduced* almanac data *of a SV is broadcast in a packet of 31 bits long, as described in Figure 20-16. The reduced almanac data* are a subset of the *almanac data which provide less precise* ephemeris. *The reduced almanac data values are provided relative to pre-specified reference values.* The number of bits, the scale factor (LSB), the range, and the units of the *reduced* almanac parameters are given in Table 20-V. The algorithms and other material related to the use of the *reduced* almanac data are given in *Section* 20.3.3.4.*6.*2.

The *reduced* almanac parameters shall be updated by the CS at least once every *3* days while the CS is able to upload the SVs. If the CS is unable to upload the SVs, the accuracy of the *reduced* almanac parameters transmitted by the SVs will degrade over time.

20.3.3.4.6.2 Reduced Almanac Packet. The following shall apply when interpreting the data provided in each packet of reduced almanac (see Figure 20-16).

20.3.3.4.6.2.1 Reduced Almanac. The reduced almanac data is provided in bits 7 through 28 of each packet. The data from a packet along with the reference values (see Table 20-V) provide ephemeris with further reduced precision. The user algorithm is essentially the same as the user algorithm used for computing the precise ephemeris from the parameters of the Message Types 10 and 11 (see paragraph 20.3.3.1.3 and Table 20-II). Other parameters appearing in the equations of Table 20-II, but not provided by the reduced almanac with the reference values, are set to zero for SV position determination.
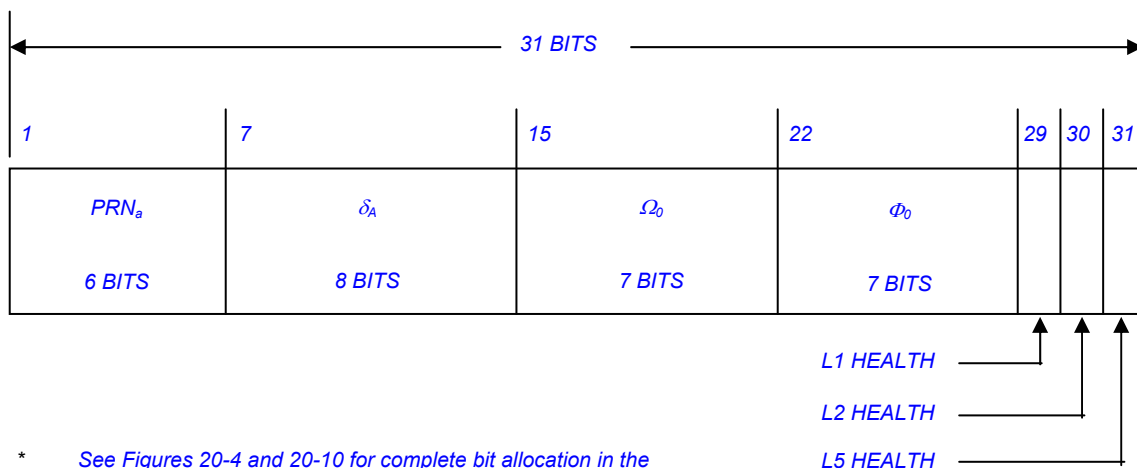
31 BITS

1	7	15	22	29	30	31
PRN$_a$ 6 BITS	δ_A 8 BITS	Ω_0 7 BITS	Φ_0 7 BITS			

L1 HEALTH

L2 HEALTH

L5 HEALTH

* See Figures 20-4 and 20-10 for complete bit allocation in the respective messages.

Figure 20-16 Reduced Almanac Packet Content

Table 20-V. Reduced Almanac Parameters *****				
Parameter	No. of Bits	Scale Factor (LSB)	Effective Range **	Units
δ_A ***	8 *	2^{+9}	**	meters
Ω_0	7 *	2^{-6}	**	semi-circles
Φ_0 ****	7 *	2^{-6}	**	semi-circles

* Parameters so indicated shall be two's complement with the sign bit (+ or -) occupying the MSB;

** Effective range is the maximum range attainable with indicated bit allocation and scale factor;

*** Relative to A_{ref} = 26,559,710 meters;

**** Φ_0 = Argument of Latitude at Reference Time = $M_0 + \omega$;

***** Relative to following reference values:

$e = 0$

$\delta_i = +0.0056$ semi-circles (i = 55 degrees)

$\Omega\text{-}DOT = -2.6 \times 10^{-9}$ semi-circles/second

20.3.3.5 Message Type 32 Earth Orientation Parameters (EOP). The earth orientation parameters ar provided in message type 32. The parameters are defined below, followed by material pertinent to the use of the data.

20.3.3.5.1 EOP Content. Message type 32, Figure 20-5, provides SV clock correction parameters (ref. Section 20.3.3.2) and earth orientation parameters. The EOP message provides users with parameters to construct the ECEF and ECI coordinate transformation. The number of bits, scale factors (LSBs), the range, and the units of all EOP fields of message type 32 are given in Table 20-VI.

20.3.3.5.2 User Algorithm for Application of the EOP. The EOP fields in the message type 32 contain the EOP needed to construct the ECEF-to-ECI coordinate transformation. The user computes the ECEF position of the SV antenna phase center using the equations shown in Table 20-II. The coordinate transformation, for translating to the corresponding ECI SV antenna phase center position, is derived using the equations shown in Table 20-VII. The coordinate systems are defined in Section 20.3.3.4.3.3 of IS-GPS-200.

An ECI position, R_{eci}, is related to an ECEF position, R_{ecef}, by a series of rotation matrices as following:

$$R_{ecef} = [A][B][C][D]R_{eci},$$

where the rotation matrices, A, B, C, and D, represent the effects of Polar Motion, Earth Rotation, Nutation and Precession, respectively. The message type 32 specifies the EOP parameters used in the construction of the Polar Motion, A, and Earth Rotation, B, matrices.

The rotation matrices, A, B, C and D are specified in terms of elementary rotation matrices $R_i(\alpha)$, where α is a positive rotation about the ith – axis ordinate, as follows:

$$R_1(\alpha) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\alpha) & \sin(\alpha) \\ 0 & -\sin(\alpha) & \cos(\alpha) \end{bmatrix} \quad , \quad R_2(\alpha) = \begin{bmatrix} \cos(\alpha) & 0 & -\sin(\alpha) \\ 0 & 1 & 0 \\ \sin(\alpha) & 0 & \cos(\alpha) \end{bmatrix}$$

$$R_3(\alpha) = \begin{bmatrix} \cos(\alpha) & \sin(\alpha) & 0 \\ -\sin(\alpha) & \cos(\alpha) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

The user shall compute the Inertial-to-Geodetic rotation matrix, ABCD using the equations shown in Table 20-VII

	Parameter	No. of Bits**	Scale Factor (LSB)	Effective Range***	Units
	Table 20-VI. Earth Orientation Parameters				
t_{EOP}	EOP Data Reference Time	16	2^4	604,784	seconds
$PM\_X^{\dagger}$	X-Axis Polar Motion Value at Reference Time.	21*	2^{-20}	1	arc-seconds
PM_X-DOT	X-Axis Polar Motion Drift at Reference Time.	15*	2^{-21}	7.8125×10^{-3}	arc-seconds/day
$PM\_Y^{\dagger\dagger}$	Y-Axis Polar Motion Value at Reference Time.	21*	2^{-20}	1	arc-seconds
PM_Y-DOT	Y-Axis Polar Motion Drift at Reference Time.	15*	2^{-21}	7.8125×10^{-3}	arc-seconds/day
$\Delta UT1^{\dagger\dagger\dagger}$	UT1-UTC Difference at Reference Time.	31*	2^{-24}	64	seconds
$\Delta UT1$-DOT †††	Rate of UT1-UTC Difference at Reference Time	19*	2^{-25}	7.8125×10^{-3}	seconds/day

* Parameters so indicated are two's complement, with the sign bit (+ or -) occupying the MSB;

** See Figure 20-5 for complete bit allocation in Message type 32;

*** Unless otherwise indicated in this column, effective range is the maximum range attainable with indicated bit allocation and scale factor.

[†] Represents the predicted angular displacement of instantaneous Celestial Ephemeris Pole with respect to semi-minor axis of the reference ellipsoid along Greenwich meridian.

[††] Represents the predicted angular displacement of instantaneous Celestial Ephemeris Pole with respect to semi-minor axis of the reference ellipsoid on a line directed 90° west of Greenwich meridian.

[†††] With zonal tides restored.

Table 20-VII. Application of EOP Parameters (Part 1 of 2)	
Element/Equation	*Description*
$TDT = t + 51\overset{s}{.}184$	*Compute Terrestrial Dynamical Time relative to GPS Time t*
J.E.D. = TDT expressed in days of 86400 sec	*Compute Julian Ephemeris Date*
$g = \dfrac{\pi}{180°}\left[\,357\overset{°}{.}528 + 35999\overset{°}{.}05\,\dfrac{J.E.D. - 2451545}{36525}\right]$	*Compute Mean Anomaly of Earth in its orbit, g*
$J.B.D. = J.E.D. + \dfrac{0\overset{s}{.}001658\sin\left(g + 0.0167\sin g\right)}{86400s}$	*Compute Julian Date in Barycentric Dynamical Time*
$T = \dfrac{J.B.D. - 2451545}{36525}$	*Compute time from J2000 Julian Epoch in Julian Centuries*
$\zeta = 2306\overset{''}{.}2181\,T + 0\overset{''}{.}30188\,T^2 + 0\overset{''}{.}017998\,T^3$ $z = 2306\overset{''}{.}2181\,T + 1\overset{''}{.}09468\,T^2 + 0\overset{''}{.}018203\,T^3$ $\theta = 2004\overset{''}{.}3109\,T - 0\overset{''}{.}42665\,T^2 - 0\overset{''}{.}041833\,T^3$	*Compute Precession Fundamental Angles at time t*
$D = R_3\left(-90° - z\right)R_1\left(\theta\right)R_3\left(90° - \zeta\right)$	*Calculate Precession Matrix at time, t*
$\bar{\varepsilon} = 23°26'21''\!.448 - 46\overset{''}{.}815\,T - 0\overset{''}{.}00059\,T^2$ $+\, 0\overset{''}{.}001813\,T^3$	*Compute Mean Obliquity, $\bar{\varepsilon}$, at time t*
$C = R_1\left(-(\bar{\varepsilon} + \Delta\varepsilon)\right)R_3\left(-\Delta\psi\right)R_1\left(\bar{\varepsilon}\right)$	*Compute Nutation Matrix at time, t*

Table 20-VII. Application of EOP Parameters (Part 2 of 2)	
Element/Equation	*Description*
$$\Delta\psi = \sum_{i=1}^{106} a_i \sin\left(\sum_{j=1}^{5} e_j \; E_j\right)^{\dagger\dagger}$$	*Nutation in Longitude*
$$\Delta\varepsilon = \sum_{i=1}^{64} b_i \cos\left(\sum_{j=1}^{5} e_j \; E_j\right)^{\dagger\dagger}$$	*Nutation in Obliquity*
UT1 = UTC + ΔUT1 + ΔUT1-DOT (t − t_{EOP})	*Compute Universal Time at time t*
$$T_U = \frac{\text{J.D.} - 2451545}{36525}$$ where J.D. $=$ UT1 expressed in days of 86400 sec	*Compute Universal Time from J2000 Julian Epoch in Julian Centuries*
$$\bar{\alpha} = \frac{2\pi}{24^h}\left(\begin{array}{l} UT1 + 6^h 41^m 50\overset{s}{.}54841 \\ + 8640184\overset{s}{.}812866 T_U \\ + 0\overset{s}{.}093104 T_U^2 - 6\overset{s}{.}2 \times 10^{-6} T_U^3 \end{array}\right)$$	*Compute Mean Greenwich Hour Angle*
$\alpha = \bar{\alpha} + \Delta\psi \; \cos(\bar{\varepsilon} + \Delta\varepsilon)$	*Compute True Greenwich Hour Angle*
$B = R_3\left(\alpha\right)$	*Compute Rotation Matrix at time, t*
$A = R_2\left(-x_p\right) R_1\left(-y_p\right)$ where $x_p = PM\_X + PM\_X - Dot \cdot \left(t - t_{TO}\right)$ $y_p = PM\_Y + PM\_Y - Dot \cdot \left(t - t_{TO}\right)$	*Compute Polar Motion Matrix at time, t*
$ABCD = \left[A\right]\left[B\right]\left[C\right]\left[D\right]$	*Compute Inertial-to-Geodetic Rotation matrix, ABCD*

T is GPS system time at time of transmission, i.e., GPS time corrected for transit time (range/speed of light).

[††] *The Nutation in Longitude and the Nutation in Obliquity are as described in The Astronomical Almanac (1983), pp. S23-S26, evaluated at time T.*

20.3.3.*6* *Message Type 33* Coordinated Universal Time (UTC) Parameters. *Message type 33, Figure 20-6, contains the UTC parameters. The contents of message type 33 are defined below, followed by material pertinent to the use of the UTC data.*

20.3.3.6.1 UTC Parameter Content. *Message type 33 provides SV clock correction parameters (ref. Section 20.3.3.2) and also, shall contain the parameters related to correlating UTC (USNO) time with GPS Time. The bit lengths, scale factors, ranges, and units of these parameters are given in Table 20-VIII. See Figure 20-6 for complete bit allocation in message type 33.*

The parameters relating GPS time to UTC (USNO) shall be updated by the CS at least once every three days while the CS is able to upload the SVs. If the CS is unable to upload the SVs, the accuracy of the UTC parameters transmitted by the SVs will degrade over time.

20.3.3.*6*.2 UTC and GPS Time. *Message type 33 includes: (1) the parameters needed to relate GPS Time to UTC(USNO), and (2) notice to the user regarding the scheduled future or recent past (relative to NAV message upload) value of the delta time due to leap seconds (Δt_{LSF}), together with the week number (WN_{LSF}) and the day number (DN) at the end of which the leap second becomes effective. Information required using these parameters to calculate t_{UTC} is in paragraph 20.3.3.5.2.4 of IS-GPS-200 except the following definition of Δt_{UTC} shall be used.*

$$\Delta t_{UTC} = \Delta t_{LS} + A_{0\text{-}n} + A_{1\text{-}n} (t_E - t_{ot} + 604800 (WN - WN_{ot})) + A_{2\text{-}n} (t_E - t_{ot} + 604800 (WN - WN_{ot}))^2 \text{ seconds}$$

	Parameter	No. of Bits**	Scale Factor (LSB)	Effective Range***	Units
	Table 20-VIII. UTC Parameters				
A_{0-n}	Bias coefficient of GPS time scale relative to UTC time scale	16*	2^{-35}		Seconds
A_{1-n}	Drift coefficient of GPS time scale relative to UTC time scale	13*	2^{-51}		sec/sec
A_{2-n}	Drift rate correction coefficient of GPS time scale relative of UTC time scale	7*	2^{-68}		sec/sec^2
Δt_{LS}	Current or past leap second count	8*	1		seconds
t_{ot}	Time data reference Time of Week	16	2^4	602,112	seconds
WN_{ot}	Time data reference Week Number	13	1		weeks
WN_{LSF}	Leap second reference Week Number	8	1		weeks
DN	Leap second reference Day Number	4****	1		days
Δt_{LSF}	Current or future leap second count	8*	1		seconds

   *   *Parameters so indicated shall be two's complement with the sign bit (+ or -) occupying the MSB;*
  **   *See Figure 20-6 for complete bit allocation*
 ***   *Unless otherwise indicated in this column, effective range is the maximum range attainable with indicated bit allocation and scale factor;*
****   *Right justified.*

20.3.3.7   Message Types 34, 13, and 14 Differential Correction Parameters. Differential Correction (DC) parameters are provided either in message types 34, or in types 13 and 14. These parameters provide users with sets of correction terms that apply to the clock and ephemeris data transmitted by other SVs. DC parameters are grouped in packets, as described in the next sections. The availability of these message types is subject to the control and determination of the CS.

20.3.3.7.1   Differential Correction Parameters Content. Message type 34 provides SV clock correction parameters (ref. Section 20.3.3.2) and also, shall contain DC parameters that apply to the clock and ephemeris data transmitted by another SV. One message type 34, Figure 20-7, shall contain 34 bits of clock differential correction (CDC) parameters and 92 bits of ephemeris differential correction (EDC) parameters for one SV other than the transmitting SV. Bit 150 of message type 34 shall be a DC Data Type indicator that indicates the data type for which the DC parameters apply. Zero (0) signifies that the corrections apply to CNAV data, $D_5(t)$, and one (1) signifies that the corrections apply to NAV data, D(t), described in Appendix II of IS-GPS-200.

Message types 13 and 14 together also provide DC parameters. Message type 13, Figure 20-11, shall contain CDC parameters applicable to 6 SVs and message type 14, Figure 20-12, shall contain EDC parameters applicable to 2 SVs. There shall be a DC Data Type indicator preceding each CDC or EDC packet. The content of an individual data packet is depicted in Figure 20-17. The number of bits, scale factors (LSB), the range, and the units of all fields in the DC packet are given in Table 20-IX.

20.3.3.7.2   DC Data Packet. Each DC data packet contains: corrections to SV clock polynomial coefficients provided in any one of the message types 30 to 36 of the corresponding SV; corrections to quasi-Keplerian elements referenced to t_{od} of the corresponding SV; User Differential Range Accuracy (UDRA) and UDRA-DOT indices that enables users to estimate the accuracy obtained after corrections are applied. Each DC packet is made up of two different segments. The first segment contains 34 bits for the CDC parameters and the second segment contains 92 bits of EDC parameters totaling 126 bits. The CDC and EDC parameters form an indivisible pair and users must utilize CDC and EDC as a pair. Users must utilize CDC and EDC data pair of same t_{op-D} and of same t_{OD}.

20.3.3.7.2.1   Differential Correction Data Predict Time of Week. The DC data predict time of week (t_{op-D}) provides the epoch time of week, in increments of 300 seconds (i.e. five minutes), at which the prediction for the associated DC data was performed.

20.3.3.7.2.2 _Time of Differential Correction Data_. The time of DC data, t_{OD}, specifies the reference time of week, in increments of 300 seconds (i.e., five minutes) relative to the GPS week, for the associated CDC and EDC data.

20.3.3.7.2.3 _SV PRN Identification_. The PRN ID of both CDC and EDC of Figure 20-17 identifies the satellite to which the subject 126-bit differential correction packet data applies (by PRN code assignment). A value of all ones "11111111" in any PRN ID field shall indicate that no DC data is contained in the remainder of the data block. In this event, the remainder of the data block shall be filler bits, i.e., alternating ones and zeros beginning with one.
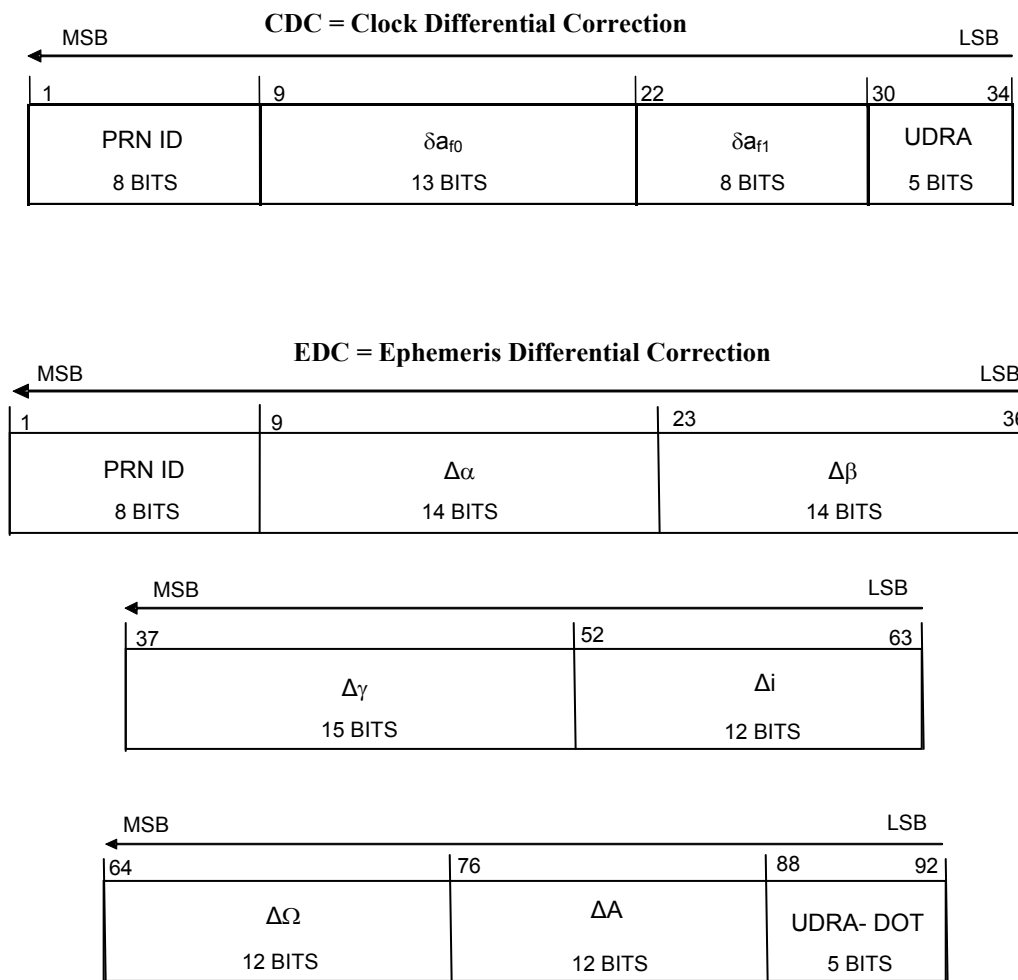
CDC = Clock Differential Correction

MSB →   LSB

1	9	22	30 34
PRN ID 8 BITS	δa_{f0} 13 BITS	δa_{f1} 8 BITS	UDRA 5 BITS

EDC = Ephemeris Differential Correction

MSB →   LSB

1	9	23 36
PRN ID 8 BITS	$\Delta\alpha$ 14 BITS	$\Delta\beta$ 14 BITS

MSB →   LSB

37	52 63
$\Delta\gamma$ 15 BITS	Δi 12 BITS

MSB →   LSB

64	76	88 92
$\Delta\Omega$ 12 BITS	ΔA 12 BITS	UDRA- DOT 5 BITS

Figure 20-17 Differential Correction Data Packet

Table 20-IX. Differential Correction Parameters

Parameter		No. of Bits**	Scale Factor (LSB)	Effective Range***	Units
PRN ID		8			see text
δa_{f0}	SV Clock Bias Correction	13*	2^{-35}		seconds
δa_{f1}	SV Clock Drift Correction	8*	2^{-51}		seconds/second
UDRA	User Differential Range Accuracy Index.	5*			see text
$\Delta\alpha$	Alpha Correction to Ephemeris Parameters	14*	2^{-34}		dimensionless
$\Delta\beta$	Beta Correction to Ephemeris Parameters	14*	2^{-34}		dimensionless
$\Delta\gamma$	Gamma Correction to Ephemeris Parameters	15*	2^{-32}		semi-circles
Δi	Angle of Inclination Correction	12*	2^{-32}		semi-circles
$\Delta\Omega$	Angle of Right Ascension Correction	12*	2^{-32}		semi-circles
ΔA	Semi-Major Correction	12*	2^{-9}		meters
UDRA-DOT	Change Rate of User Differential Range Accuracy Index	5*			see text

*   Parameters so indicated are two's complement, with the sign bit (+ or -) occupying the MSB;

**   See Figure 20-7, 11 and 12 for complete bit allocation in message types 34, 13 and 14.

***   Unless otherwise indicated in this column, effective range is the maximum range attainable with indicated bit allocation and scale factor.

20.3.3.7.3 _Application of Clock-Related DC Data._ _The SV PRN code phase offset, uncorrected by clock correction coefficient updates, is given by equation 2 in 20.3.3.3.1 of IS-GPS-200 (see paragraph 20.3.3.2.3). If the matched pair of DC data for the subject SV is available, the user may apply clock correction coefficient update values by;_

$$\Delta t_{sv} = (a_{f0} + \delta a_{f0}) + (a_{f1} + \delta a_{f1})(t - t_{oc}) + a_{f2}(t - t_{oc})^2 + \Delta t_r$$

where δa_{f0} and δa_{f1}, (see Table 20-IX), are given in message types 34 or 13, and all other terms are as stated in 20.3.3.3.1 of IS-GPS-200. Clock-related DC data shall not be applied to any SV transmitting clock correction parameters message(s) containing a t_{op} value greater than the t_{op-D} value of messages types 34 or 13 containing the clock-related DC data.

20.3.3.7.4 _Application of Orbit-Related DC Data._ _The DC data packet includes corrections to parameters that correct the state estimates for ephemeris parameters transmitted in the message types 10 and 112 (broadcast by the SV to which the DC data packet applies). The user will update the ephemeris parameters utilizing a variation of the algorithm expressed in the following equations. The user will then incorporate the updated quasi-Keplerian element set in all further calculations of SV position, as represented by the equations in Table 20-II (see para. 20.3.3.1.3). Ephemeris-related DC data shall not be applied to any SV transmitting message types 10 and 11 containing a t_{op} value greater than the t_{op-D} value of message types 34 or 14 containing the ephemeris-related DC data._

The user will construct a set of initial (uncorrected) elements by:

$$A_i \quad = \quad A_0$$

$$e_i \quad = \quad e_n$$

$$i_i \quad = \quad i_{0-n}$$

$$\Omega_i \quad = \quad \Omega_{0-n}$$

$$\alpha_i \quad = \quad e_n \cdot cos(\omega_n)$$

$$\beta_i \quad = \quad e_n \cdot sin(\omega_n)$$

$$\gamma_i \quad = \quad M_{0-n} + \omega_n$$

where A_0, e_n, i_{0-n}, Ω_{0-n}, ω_n and M_{0-n} are obtained from the applicable SV's message types 10 and 11 data. The terms α_i, β_i, and γ_i form a subset of stabilized ephemeris elements which are subsequently corrected by $\Delta\alpha$, $\Delta\beta$ and $\Delta\gamma$—the values of which are supplied in the message types 34 or 14—as follows:

$$\alpha_c = \alpha_i + \Delta\alpha$$

$$\beta_c = \beta_i + \Delta\beta$$

$$\gamma_c = \gamma_i + \Delta\gamma$$

The quasi-Keplerian elements are then corrected by

$$A_c = A_i + \Delta A$$

$$e_c = (\alpha_c^2 + \beta_c^2)^{1/2}$$

$$i_c = i_0 + \Delta i$$

$$\Omega_c = \Omega_0 + \Delta\Omega$$

$$\omega_c = \tan^{-1} (\beta_c/\alpha_c)$$

$$M_{0\_c} = \gamma_c - \omega_c + \Delta M_0$$

where ΔA, Δi and $\Delta\Omega$ are provided in the EDC data packet of the message type 34 or 14 and ΔM_0 is obtained from

$$\Delta M_0 = -3*(\mu^{1/2})/A_c^2*[(t_{oe}) - (t_{OD})].$$

The corrected quasi-Keplerian elements above are applied to the user algorithm for determination of antenna phase center position in Section 20.3.3.1.3, Table 20-II.

20.3.3.7.5 SV Differential Range Accuracy Estimates. The UDRA$_{op-D}$ and UDRA-DOT shall give the differential user range accuracy for the SV. It must be noted that the two parameters provide estimated accuracy after both clock and ephemeris DC are applied. The UDRA$_{op-D}$ and UDRA-DOT indices are signed, two's complement integers in the range of +15 to –16 and has the following relationship:

Index Value	*UDRA$_{op-D}$ (meters)*					*UDRA-DOT (10^{-6} m/sec)*
15	*6144.00*	*<*	*UDRA$_{op-D}$*		*6144.00*	
14	*3072.00*	*<*	*UDRA$_{op-D}$*	*≤*	*6144.00*	*3072.00*
13	*1536.00*	*<*	*UDRA$_{op-D}$*	*≤*	*3072.00*	*1536.00*
12	*768.00*	*<*	*UDRA$_{op-D}$*	*≤*	*1536.00*	*768.00*
11	*384.00*	*<*	*UDRA$_{op-D}$*	*≤*	*768.00*	*384.00*
10	*192.00*	*<*	*UDRA$_{op-D}$*	*≤*	*384.00*	*192.00*
9	*96.00*	*<*	*UDRA$_{op-D}$*	*≤*	*192.00*	*96.00*
8	*48.00*	*<*	*UDRA$_{op-D}$*	*≤*	*96.00*	*48.00*
7	*24.00*	*<*	*UDRA$_{op-D}$*	*≤*	*48.00*	*24.00*
6	*13.65*	*<*	*UDRA$_{op-D}$*	*≤*	*24.00*	*13.65*
5	*9.65*	*<*	*UDRA$_{op-D}$*	*≤*	*13.65*	*9.65*
4	*6.85*	*<*	*UDRA$_{op-D}$*	*≤*	*9.65*	*6.85*
3	*4.85*	*<*	*UDRA$_{op-D}$*	*≤*	*6.85*	*4.85*
2	*3.40*	*<*	*UDRA$_{op-D}$*	*≤*	*4.85*	*3.40*
1	*2.40*	*<*	*UDRA$_{op-D}$*	*≤*	*3.40*	*2.40*
0	*1.70*	*<*	*UDRA$_{op-D}$*	*≤*	*2.40*	*1.70*
-1	*1.20*	*<*	*UDRA$_{op-D}$*	*≤*	*1.70*	*1.20*
-2	*0.85*	*<*	*UDRA$_{op-D}$*	*≤*	*1.20*	*0.85*
-3	*0.60*	*<*	*UDRA$_{op-D}$*	*≤*	*0.85*	*0.60*
-4	*0.43*	*<*	*UDRA$_{op-D}$*	*≤*	*0.60*	*0.43*
-5	*0.30*	*<*	*UDRA$_{op-D}$*	*≤*	*0.43*	*0.30*
-6	*0.21*	*<*	*UDRA$_{op-D}$*	*≤*	*0.30*	*0.21*
-7	*0.15*	*<*	*UDRA$_{op-D}$*	*≤*	*0.21*	*0.15*
-8	*0.11*	*<*	*UDRA$_{op-D}$*	*≤*	*0.15*	*0.11*
-9	*0.08*	*<*	*UDRA$_{op-D}$*	*≤*	*0.11*	*0.08*
-10	*0.06*	*<*	*UDRA$_{op-D}$*	*≤*	*0.08*	*0.06*
-11	*0.04*	*<*	*UDRA$_{op-D}$*	*≤*	*0.06*	*0.04*
-12	*0.03*	*<*	*UDRA$_{op-D}$*	*≤*	*0.04*	*0.03*
-13	*0.02*	*<*	*UDRA$_{op-D}$*	*≤*	*0.03*	*0.02*
-14	*0.01*	*<*	*UDRA$_{op-D}$*	*≤*	*0.02*	*0.01*
-15			*UDRA$_{op-D}$*	*≤*	*0.01*	*0.005*
-16	*No accuracy prediction available—use at own risk*					

For any time, t_k, other than t_{op-D}, UDRA is found by,

$$UDRA = UDRA_{op-D} + UDRA\text{-DOT } (t_k - t_{op-D})$$

20.3.3.8 *Message Type 35 GPS/GNSS Time Offset*. Message type 35, Figure 20-8, contains the GPS/Global Navigation Satellite System (GNSS) Time Offset (GGTO) parameters. The contents of message type 35 are defined below. The validity period of the GGTO shall be 1 day as a minimum.

20.3.3.8.1 GPS/GNSS Time Offset Parameter Content. Message Type 35 provides SV clock correction parameters (ref. Section 20.3.3.2) and also, shall contain the parameters related to correlating GPS time with other GNSS time. Bits 155 through 157 of message type 35 shall identify the other GPS like navigation system to which the offset data applies. The three bits are defined as follows;

> *000 = no data available,*
> *001 = Galileo,*
> *010 = GLONASS,*
> *011 through 111 = reserved for other systems.*

The number of bits, the scales factor (LSB), the range, and the units of the GGTO parameters are given in Table 20-X. See Figure 20-8 for complete bit allocation in message type 35.

20.3.3.8.2 GPS and GNSS Time. The GPS/GNSS-time relationship is given by,

$$t_{GNSS} = t_E - (A_{0GGTO} + A_{1GGTO} (t_E - t_{otGGTO} + 604800 (WN - WN_{otGGTO}) + A_{2GGTO} (t_E - t_{otGGTO} + 604800 (WN - WN_{otGGTO}))^2)$$

where t_{GNSS} is in seconds, t_E and WN are as defined in Section 20.3.3.5.2.4 of IS-GPS-200, and the remaining parameters are as defined in Table 20-X.

	Table 20-X. GPS/GNSS Time Offset Parameters				
	Parameter	*No. of Bits***	*Scale Factor (LSB)*	*Effective Range****	*Units*
A_{0GGTO}	*Bias coefficient of GPS time scale relative to GNSS time scale*	*16**	2^{-35}		*seconds*
A_{1GGTO}	*Drift coefficient of GPS time scale relative to GNSS time scale*	*13**	2^{-51}		*sec/sec*
A_{2GGTO}	*Drift rate correction coefficient of GPS time scale relative to GNSS time scale*	*7**	2^{-68}		*sec/sec^2*
t_{otGGTO}	*Time data reference Time of Week*	*16*	2^4	*604,784*	*seconds*
WN_{otGGTO}	*Time data reference Week Number*	*13*	2^0		*weeks*
GNSS ID	GNSS Type ID	*3*			*see text*

* Parameters so indicated shall be two's complement with the sign bit (+ or -) occupying the MSB;

** See Figure 20-8 for complete bit allocation;

*** Unless otherwise indicated in this column, effective range is the maximum range attainable with indicated bit allocation and scale factor.

20.3.3.*9* Message Types *36 and 15 Text Messages*. *Text messages are provided either in message type 36, Figure 20-9, or type 15, Figure 20-13*. The specific contents *of text message will be* at the discretion of the Operating Command. *Message type 36 can accommodate the transmission of 18 eight-bit ASCII characters. Message type 15* can accommodate the transmission of 29 eight-bit ASCII characters. *The requisite bits shall occupy bits 39 through 270 of message type 15 and bits 128 through 275 of message type 36*. The eight-bit ASCII characters shall be limited to the set described in paragraph 20.3.3.5.1.8 of IS-GPS-200.

20.3.4 <u>Timing Relationships</u>. The following conventions shall apply.

20.3.4.1 <u>Paging and Cutovers</u>. *Broadcast system* of messages is completely arbitrary, but sequenced to provide optimum user performance. Message types 10 and 11 shall be broadcast at least once every 24 seconds. All other messages shall be broadcast in-between, not exceeding the maximum *broadcast* interval in Table 20-*XI*. Message type 15 will be broadcast as needed, but will not reduce the maximum *broadcast* interval of the other messages. Type 15 messages that are longer than one page will not necessarily be broadcast consecutively.

Table 20-*XI*. Message Broadcast Intervals		
Message Data	**Message Type Number**	**Maximum Broadcast Intervals** *†*
Ephemeris	*10 & 11*	24 sec
Clock	*Type 30 s*	24 sec
ISC, IONO	*30 **	*144 sec*
Reduced Almanac	*31* or 12*	*30 min***
Almanac	*16*	*120 min***
EOP	*32**	*15 min*
UTC	*33**	*144 sec*
Diff Correction	*34* or 13 & 14*	*15 min****
GGTO	*35**	*144 sec*
Text	*36* or 15*	As needed

*   *Also contains SV clock correction parameters.*
** *Complete set of SVs in the constellation.*
*** *When Differential Corrections are available.*

†   The intervals specified are maximum. As such, the broadcast intervals may be shorter than the specified value.

20.3.4.2 SV Time vs. GPS Time. In controlling the SVs and uploading of data, the CS shall allow for the following timing relationships:

      a.   Each SV operates on its own SV time;

      b.   All time-related data (TOW) in the messages shall be in SV-time;

      c.   All other data in the NAV message shall be relative to GPS time;

      d.   The acts of transmitting the NAV messages shall be executed by the SV on SV time.

20.3.4.3 Speed of Light. *The speed of light used by the CS for generating the data described in the above paragraphs is*

$$c = 2.99792458 \times 10^8 \qquad meters\ per\ second$$

which is the official WGS-84 speed of light. The user shall use the same value for the speed of light in all computations.

20.3.5 _Data Frame Parity_. The data signal contains parity coding according to the following conventions.

20.3.5.1 Parity Algorithm. Twenty-four bits of CRC parity will provide protection against burst as well as random errors with a probability of undetected error $\leq 2^{-24} = 5.96 \times 10^{-8}$ for all channel bit error probabilities ≤ 0.5. The CRC word is calculated in the forward direction on a given message using a seed of 0. The sequence of 24 bits $(p_1, p_2, ..., p_{24})$ is generated from the sequence of information bits $(m_1, m_2, ..., m_{276})$ in a given message. This is done by means of a code that is generated by the polynomial.

$$g(X) = \sum_{i=0}^{24} g_i X^i$$

where

$g_i = 1$ for $i = 0, 1, 3, 4, 5, 6, 7, 10, 11, 14, 17, 18, 23, 24$
$\quad = 0$ otherwise

This code is called CRC-24Q. The generator polynomial of this code is in the following form (using binary polynomial algebra):

$$g(X) = (1 + X)p(X)$$

where $p(X)$ is the primitive and irreducible polynomial

$$p(X) = X^{23} + X^{17} + X^{13} + X^{12}$$
$$+ X^{11} + X^9 + X^8 + X^7 + X^5 + X^3 + 1$$

When, by the application of binary polynomial algebra, the above $g(X)$ is divided into $m(X)X^{24}$, where the information sequence $m(X)$ is expressed as

$$m(X) = m_k + m_{k-1}X + m_{k-2}X^2 + \cdots + m_1 X^{k-1}$$

The result is a quotient and a remainder R(X) of degree < 24. The bit sequence formed by this remainder represents the parity check sequence. Parity bit p_i, for any *i* from 1 to 24, is the coefficient of X^{24-i} in R(X).

This code has the following characteristics:

1) It detects all single bit errors per code word.

2) It detects all double bit error combinations in a codeword because the generator polynomial g(X) has a factor of at least three terms.

3) It detects any odd number of errors because g(X) contains a factor 1+X.

4) It detects any burst error for which the length of the burst is ≤ 24 bits.

5) It detects most large error bursts with length greater than the parity length r = 24 bits. The fraction of error bursts of length b > 24 that are undetected is:

a) $2^{-24} = 5.96 \times 10^{-8}$, if b > 25 bits.

b) $2^{-23} = 1.19 \times 10^{-7}$, if b = 25 bits.